Macro Base Station Transceivers 2019

Abstract: This report provides a forecast for RAN infrastructure above 40W and below 6 GHz…often called Macro Base Stations. 2G, 3G, 4G, and 5G details are all included. Includes details on Remote Radio Heads (RRH) or Radio Units (RU), integration with Baseband Units (BBU, DU, CU), and breakdowns of transceivers. The level of Massive MIMO is forecasted in detail, with details of power levels, frequency bands, OEM market share, and other key factors. New analysis includes illustrations of capacity deployed, level of density supported, and details of massive MIMO beams/streams.

February 2019

MOBILE EXPERTS

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MEXP-TRX-19

MACRO BASE STATION TRANSCEIVER FORECAST

February 2019

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EXECUTIVE SUMMARY

The LTE investment wave is receding, but the 5G wave is coming in quickly. During 2019, China Mobile will be ramping up deployment of 5G using Massive MIMO at 2.5 GHz, and they are expected to deploy at least 500,000 sites (1.5M RUs or higher) within the first two years.

The sudden surge of deployment in China, coupled with the shift to 64T64R radio configuration for massive MIMO, will combine to permanently alter the face of the market. Mobile Experts has been tracking the macro base station market for 12 years, with 10-15 million transceivers shipped each year. 5G and massive MIMO will shift the number of transceivers into the range of 100 million or more within the next two years.

The deployment will begin in mid-2019, but the impact is already felt in the component world, as semiconductor suppliers are already investing heavily to beef up factory capacity and to produce items that have long lead times. Several vendors are tripling their component capacity to deal with the sudden rush of orders.

Mobile Experts has validated the business case for 5G investments by working closely with operators to understand the scope of deployment, infrastructure costs, and future expectations for 5G revenue. It's clear that the top 20 operators worldwide will be investing in 5G. Several differing strategies prevail based on economic conditions, level of competition, and the current level of traffic density. But all of them need to move to 5G in order to keep up with end-user demand.

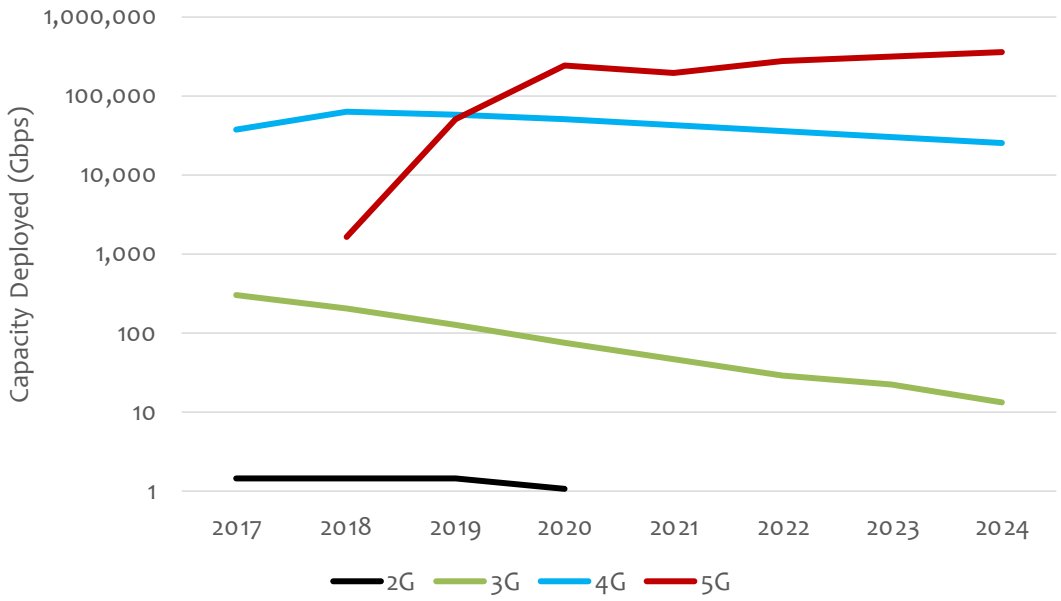
In Korea, Japan, Finland, Dubai, and many other places, 5G investment in 2019-2020 is a purely economic decision driven by ROI. In China, the calculus is different. China is driving a huge 5G investment for political reasons, as they try to move ahead of the rest of the world in telecom technology and build up their own domestic supply chain. Because this is politically driven, the inherent risk in our China forecast is tremendous. We're forecasting a nationwide 5G surge in China, and all indications currently show a major investment. ***But if the politics change, and an ROI-based approach is applied, then the Mobile Experts forecast for 5G NR deployment could drop by 70% or more in 2019 and 2020.*** In particular, the US/China trade war presents a risk, because a quick US decision to stop semiconductor shipments would completely kill the China 5G network.

Note that this forecast includes 2G through 5G macro base stations below 6 GHz. Small cells and mm-wave infrastructure are covered in separate reports, because the dynamics for these products are very different than the macro market.

On the technical side, 5G is now proven in trials with massive MIMO, real handsets, and both LTE and 5G core networks. The technical risk has been reduced significantly and we have confidence that everything works.

On the business side, 5G is expected to bring significant new capacity to the mobile market, with lower cost per GB than ever before. Operators will trigger 5G investments as their traffic density and capacity needs dictate new investments. 5G is not driven by new apps like VR… it's driven by cost reduction for simple things like mobile video. So, operators are not forced to deploy 5G as a nationwide network. Instead, some operators will deploy 5G selectively as capacity is required.

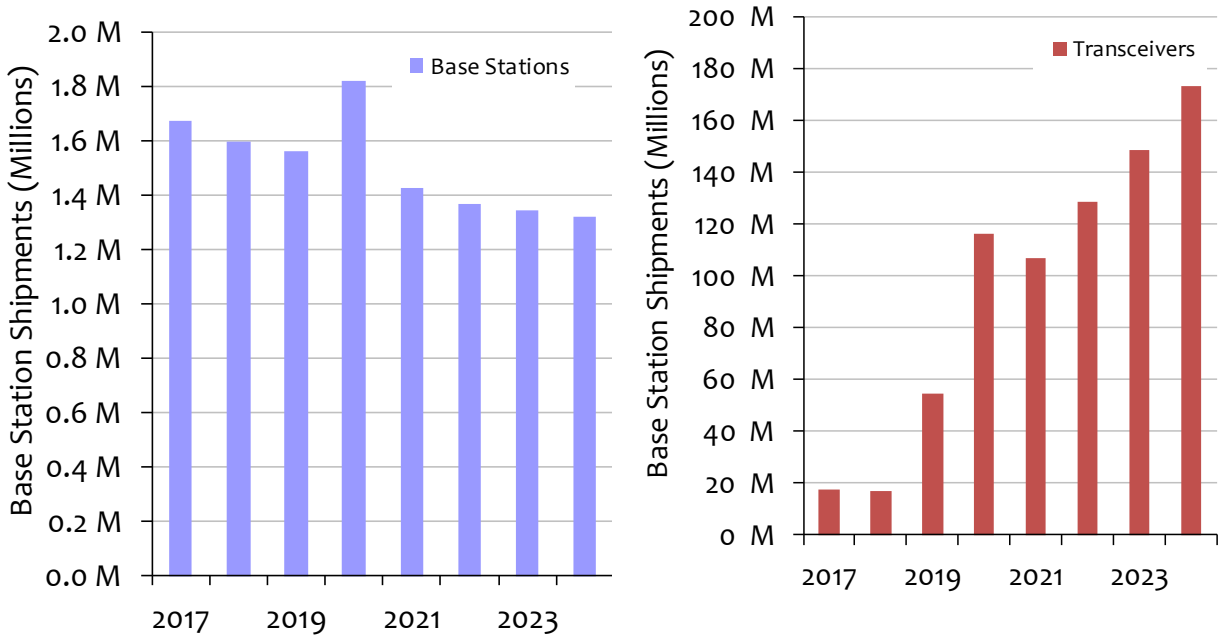
Chart 1: Mobile data capacity deployed , 2017-2024



Source: Mobile Experts.

Overall, the number of base stations sold each year will drop over the next five years, but the number of radios (and the level of capacity) will explode by an order of magnitude.

Chart 2: Forecasted Macro Base Station Transceiver Shipments by generation, 2017-2024



Source: Mobile Experts.

SECTION 1: BASE STATION FORECAST

Macro Base Station Forecast

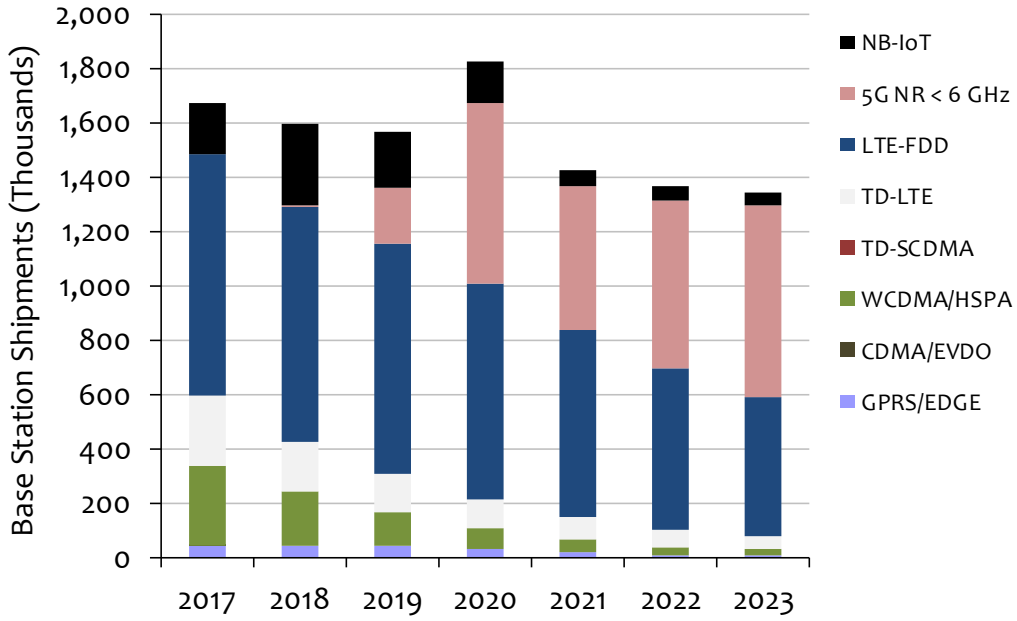
The LTE wave of deployment is clearly past its peak, so the primary story in the base station market is the expected rise of 5G. We see this as a significant shift in the deployment of mobile networks, because in most places, operators are starting to treat the network as a mature asset, adding 5G capability selectively where it's needed. Unlike 2G, 3G, and 4G transitions, we think that many 5G operators will not strive for nationwide coverage right away.

Three trends will dominate the market for macro RAN infrastructure this year:

- LTE operators will continue capacity upgrades. In many locations, one or two LTE bands have been deployed, but the operators can fill in additional bands for higher capacity.
- 5G NR deployment will take off at 2.5 and 3.5 GHz. In some cases these deployments will be huge (China), and in other cases the deployment will be limited to cities, based on capacity and hotspot requirements.
- NB-IoT base stations have been deployed quickly, and we already see this segment starting to fade. Most operators worldwide can implement NB-IoT and LTE-M through software upgrades to their existing LTE networks, so very few large operators have invested in special IoT networks.

The definition of a "base station" has lost its meaning. In the past, a base station was clearly identified as a cabinet that included radio hardware and digital baseband processing. That configuration is not used much today. Mobile Experts has continued to track the number of "base stations" deployments because many customers continue to use this terminology. To be clear, in our forecast the term "base station" refers to a single site with three or more radio units and the supporting baseband capacity (which is typically deployed in a centralized data center).

Chart 3: Forecasted Macro Base Station Shipments, 2017-2024



Source, Mobile Experts. Note: Definition of base station is RRH units and BBUs.

Centralized Base Stations and Compact BTS

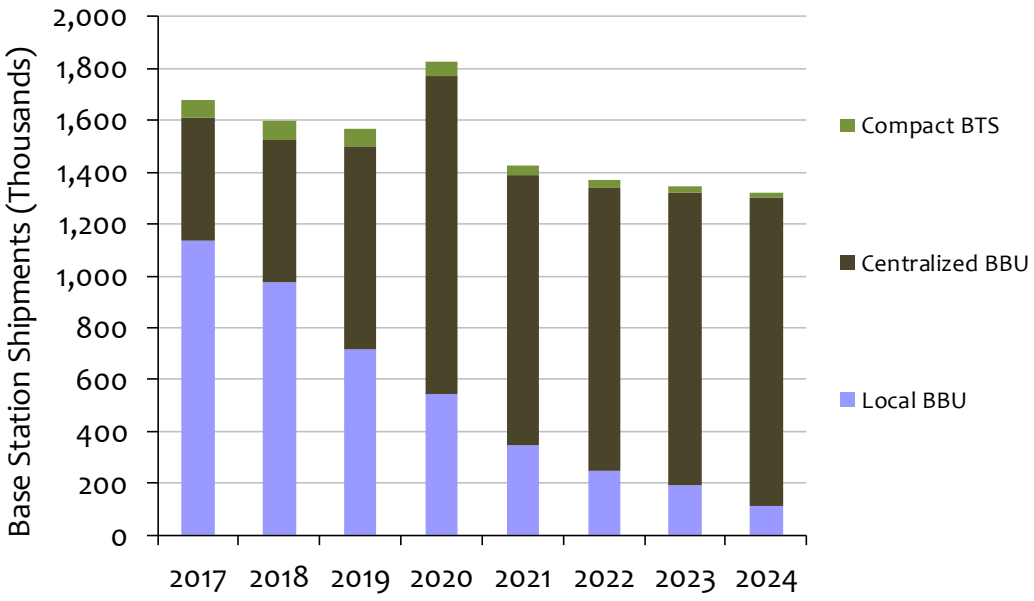
We track three different classes of Macro Base Stations: The traditional base station where the baseband unit is located at the site, base stations with centralized BBUs, and "compact BTS" architectures where the BBU and the radio unit are integrated. The majority of sites continue to use the traditional approach, but centralization and "compact BTS" formats are growing now.

The Centralized RAN architecture has clearly become the trend, as a step toward a Virtualized RAN and Edge Computing with commoditization of digital hardware. This architecture was well developed in Japan and Korea for many years but now it has become a common baseline for most operators worldwide.

Split-baseband RRH deployment will also be a useful step toward making a Centralized RAN affordable, so we include both the CPRI format and alternative split-baseband formats in our forecast for "Centralized" deployment.

Compact BTS architectures can still be used in low-capacity applications, such as rural base stations and other cases where terminating the baseband processing is more economical than carrying fiber for a long distance. In keeping with overall network investment focused on cities, we expect the compact BTS segment to remain small.

Chart 4: Base Station Shipments, Local vs Centralized vs Compact, 2016-2024

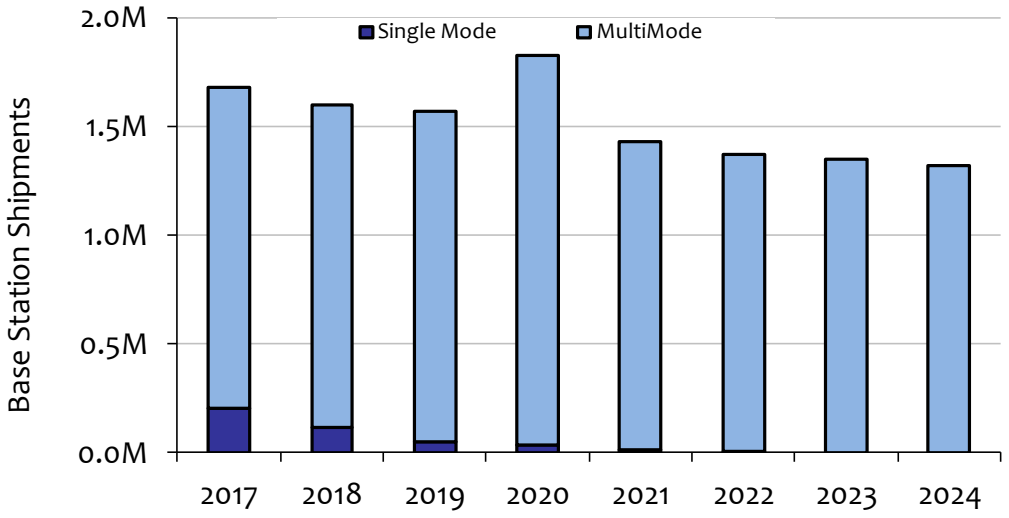


Source, Mobile Experts

Single-mode and Multi-mode Base Stations

For a long time, Mobile Experts has tracked the trend toward multi-mode capability in base station design, and we have been tracking the possibility that cost reductions or other factors will cause a resurgence of single-mode designs. That possibility looks less likely every year, as major RAN vendors are more concerned with flexibility and inventory management than BOM cost.

Chart 3: Base Station Shipments, Multimode vs. Single mode, 2017-2024

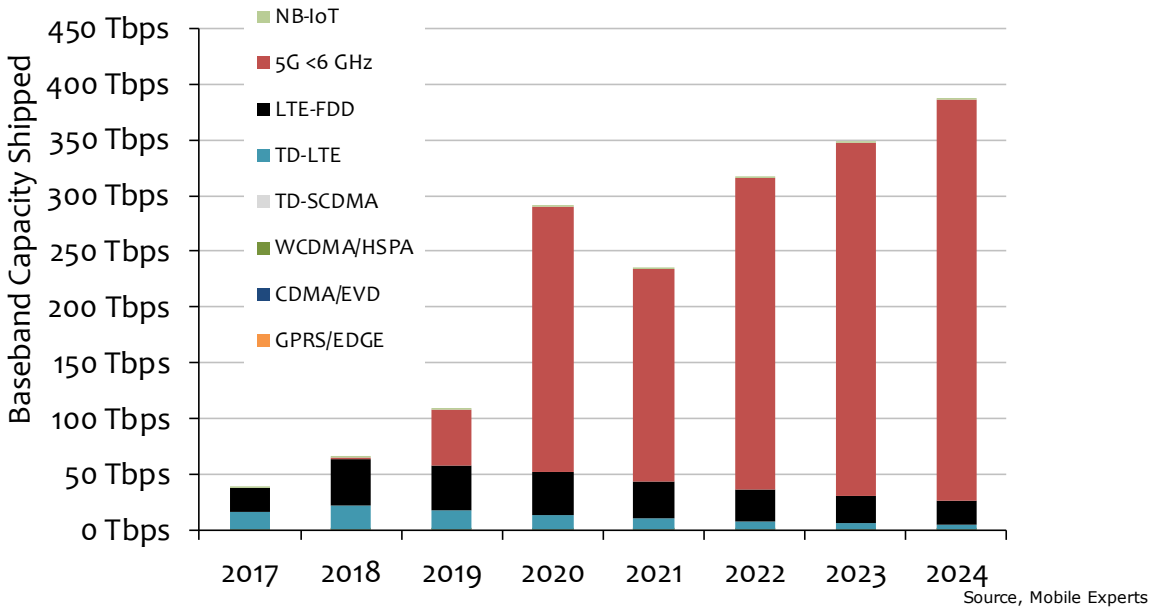


Source, Mobile Experts

Baseband Capacity Deployed

The number of 5G base stations in our forecast is smaller than 2G/3G/4G, but the level of capacity expected will be huge. The move to Massive MIMO, with higher spectral efficiency in wider channels drives a huge expansion in the capacity for each radio. Due to substantial deployment in China during 2019 using 64T massive MIMO, we expect 5G to overtake LTE in terms of the Pbps of capacity that are actually shipped!

Chart 3: Baseband Capacity Shipped in Tbps, by air interface, 2017-2024



Source, Mobile Experts

Traffic Density in the Network

As end-user demand continues to grow worldwide, we see that different levels of traffic density call for different HetNet topology. Rural networks need simple macro radio sites with high power. Urban networks need a combination of macro, small cells, and massive MIMO.

To illustrate this stratification, Mobile Experts uses benchmarking with multiple mobile operators to estimate the radio shipments used for various tiers of the market: from ultra-dense urban sites to light-density rural sites.

The thresholds between each tier of the market are based on our observations of how the operators actually invest in their networks. Above 0.02 Gbps/km2/MHz,

(0.02 GkM), operators invest in outdoor small cells. Above 0.1 Gbps/km2/MHz, they invest in massive MIMO.

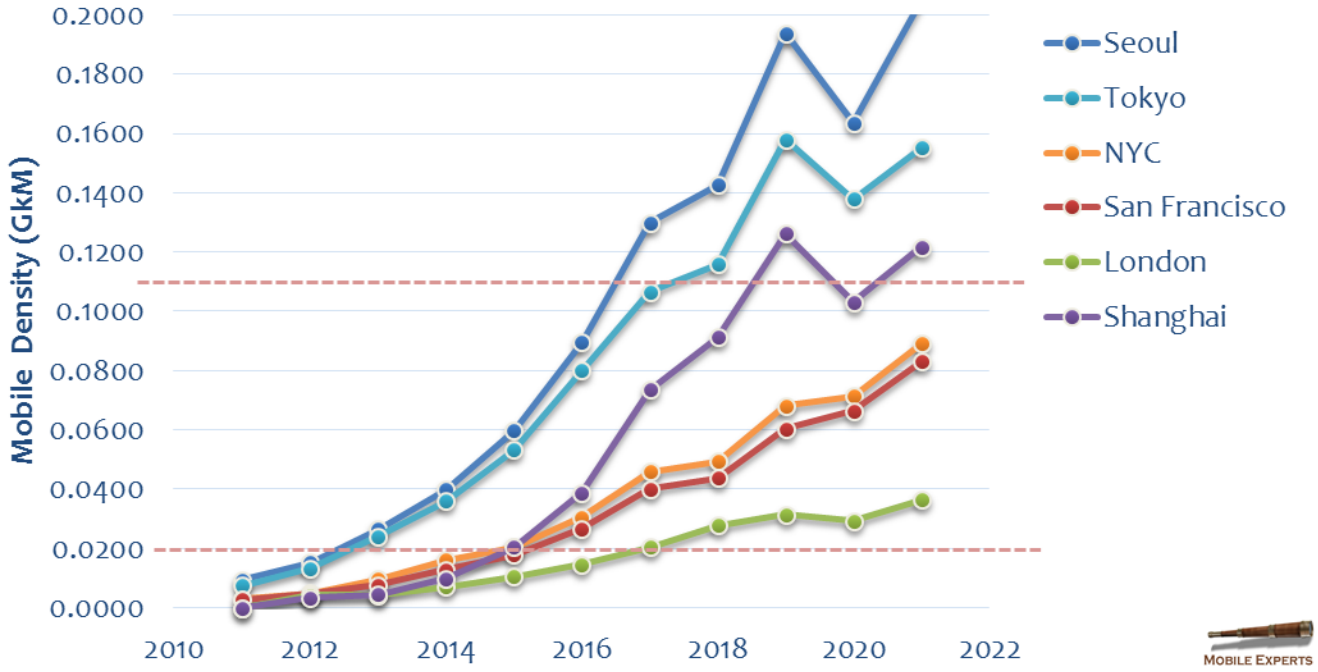


Figure 1. Traffic Density for various world cities and expecting timing of Massive MIMO

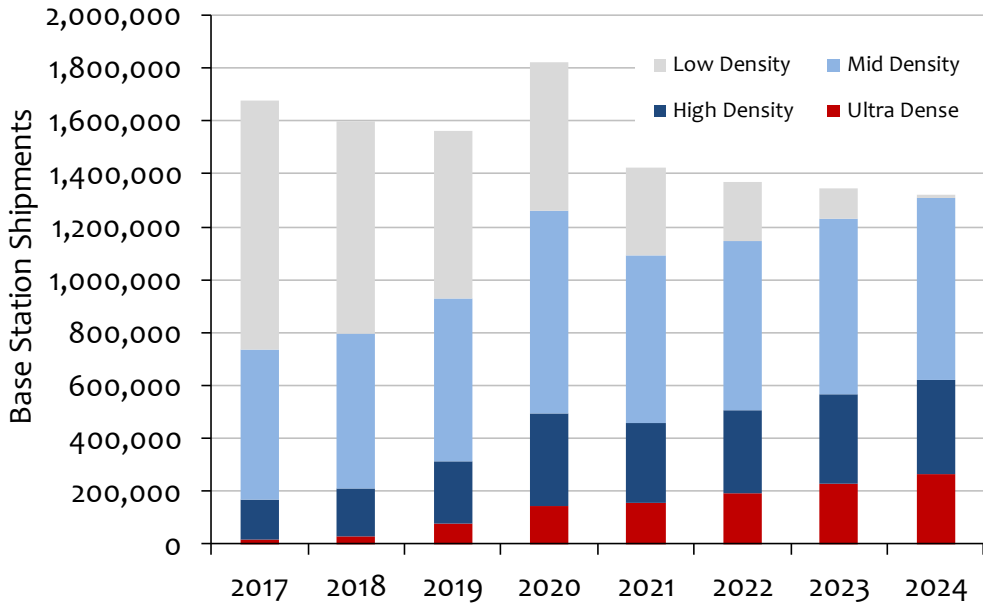
Source: Mobile Experts

With the introduction of 5G bands, we see some reductions of the traffic density (since GkM is defined as the traffic per MHz, adding more spectrum can reduce the density metric). Today, mobile traffic density has risen to unprecedented levels of 0.16 and 0.18 in Tokyo and Seoul, but the introduction of 5G bands will bring some relief in late 2019 to 2020.

To best utilize this metric, we segment our Base Station forecast into four parts:

- Base stations deployed in "Ultra dense" networks experience traffic density higher than 0.1 GkM at peak hour.
- "High density" locations handle traffic density higher than 0.02 GkM or 20 MkM. (Mbps/km2/MHz) In other words, these are base stations in areas where small cells, DAS, or heavy Wi-Fi offloading will also be utilized.
- "Mid Density" roughly corresponds with suburban areas where traffic density is between 5 MkM and 20 MkM.
- "Low Density" typically means rural installation, where traffic density is lower than 5 MkM.

Chart 5: Base Station Shipments, by density of traffic, 2017-2024



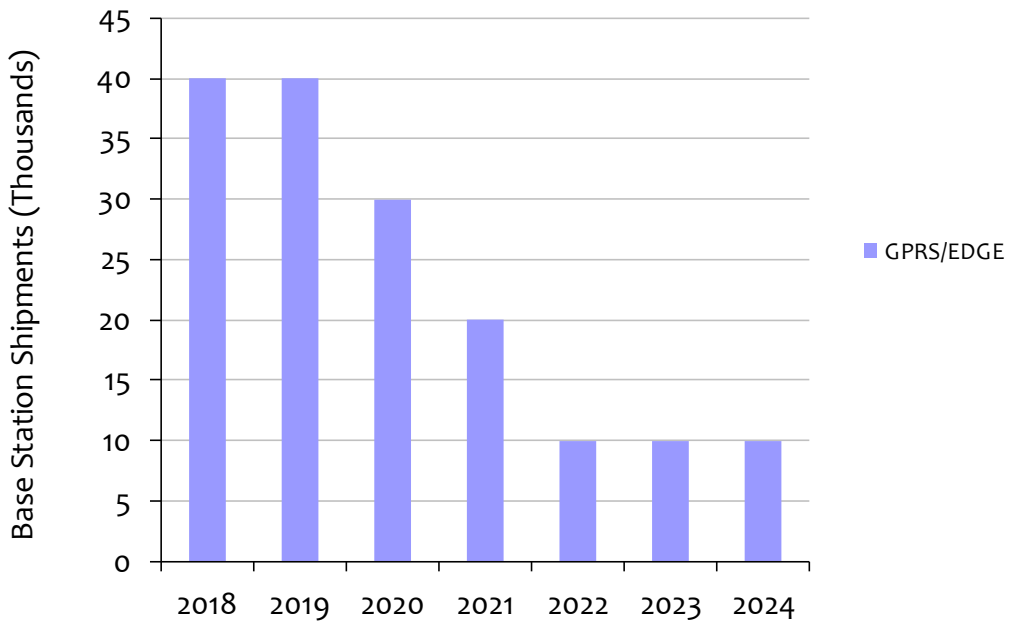
Source, Mobile Experts

GPRS and EDGE

The 3GPP standards committees have recently updated GSM/GPRS standards to optimize for IoT applications, with multiple retransmissions and long sleep cycles. However, we don't expect this to drive sales of new radio infrastructure. The only ongoing GSM/EDGE deployment is focused on poor areas of Africa, South Asia, and a few spots in Latin America. The main reason that this continues is that low-cost GSM handsets are the best option for consumers in these poor areas.

Overall, this market has become relatively insignificant because the few remaining shipments are low-cost units.

Chart 6: GSM Base Station Shipments, 2017-2024

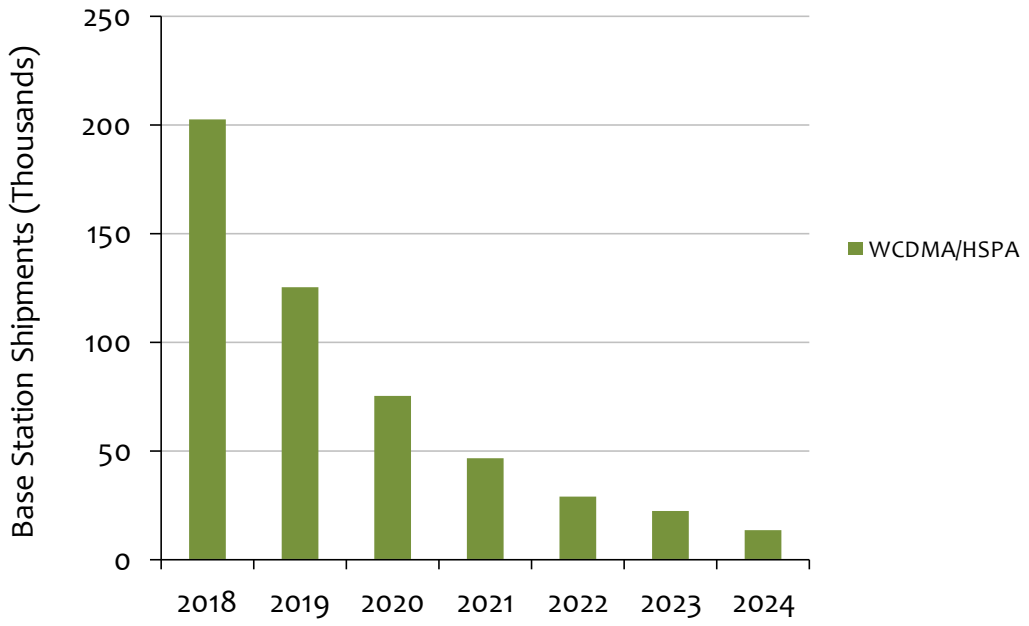


Source, Mobile Experts

WCDMA and HSPA

LTE has taken over, so HSPA/WCDMA base station deployment is steadily declining. , Some network projects in South Asia, Africa, and Latin America include ongoing deployment of 3G radio hardware, but no new projects are starting anymore. There's no reason to deploy 3G now: the phones are not the cheapest option, and the networks are not as capable as LTE. Therefore we have now revised our decline in 3G to be faster than we forecasted last year.

Chart 7: WCDMA Base Station Shipments, 2017-2024



Source, Mobile Experts

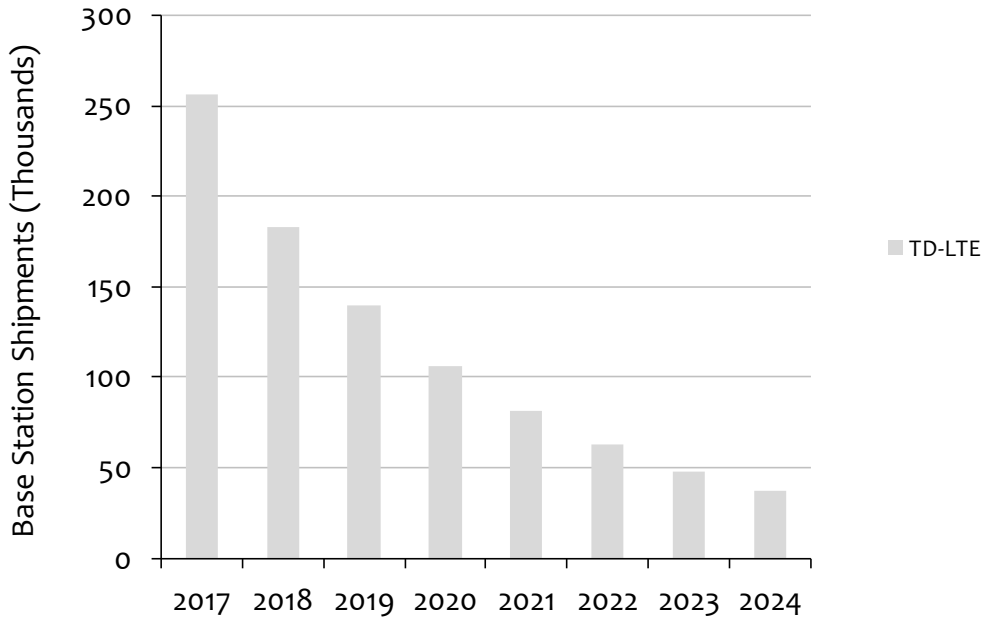
TD-LTE

The peak for TD-LTE deployment was in 2014-2015, when China Mobile deployed huge numbers of base stations nationwide. Today, China Mobile, Softbank, Sprint, Jio, and a few other operators dominate the market for TD-LTE. But the 2.5 and 3.5 GHz frequency bands where these operators use TD-LTE today will quickly convert to 5G. As a result, we expect the forecast for TD-LTE base stations to decline steadily starting in 2019.

TD-LTE operators are implementing some upgrades to Massive MIMO in the short term, and at the same time are slowing down on spending for new site deployments. They're also deploying additional radio carriers to fully utilize the wide 2.5 GHz spectrum blocks, where in some cases they're not fully utilizing the spectrum today.

There may be some baseline of ongoing deployment in South Asia, where spectrum for TD-LTE is available and the 4G equipment could be cheaper than 5G alternatives in terms of CAPEX.

Chart 8: Forecasted TD-LTE Base Station Shipments, 2017-2024



Source, Mobile Experts

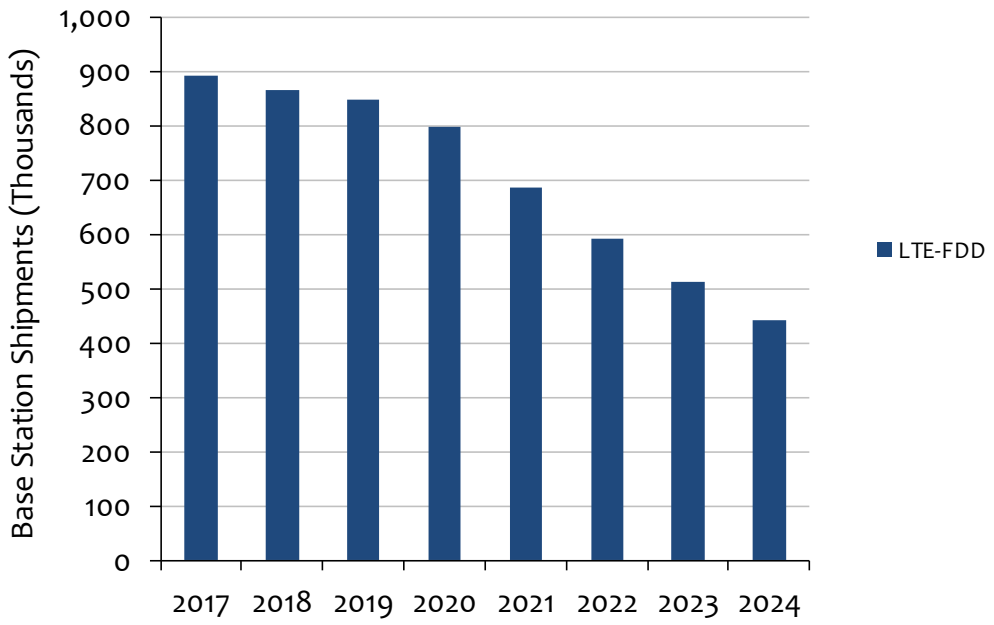
LTE-FDD

In the FDD bands, LTE deployment is continuing. There are two major forms that it takes:

1. Some operators have deployed an initial 10-20 MHz LTE channel, and have 20-30 MHz of additional spectrum to use. The logical next step is to deploy new radios with wider bandwidth, which are upgradeable someday for 5G.
2. Most LTE operators have deployed multiple bands in their dense cities, but only have one or two bands deployed in suburban or rural areas. Completing the LTE network by filling in all of the bands nationwide can be a 10-year project, because capacity is generally added only when it's needed.

Overall, we don't see a strong push to "refarm" the FDD bands to 5G. Unlike the TDD bands, these frequency bands are in lower spectrum and are generally narrower in bandwidth, so the upgrade to 5G and massive MIMO does not make economic sense. For this reason, we expect the LTE-FDD forecast to remain solid for several years.

Chart 9: LTE-FDD eNodeB Shipments, 2017-2024



Source, Mobile Experts

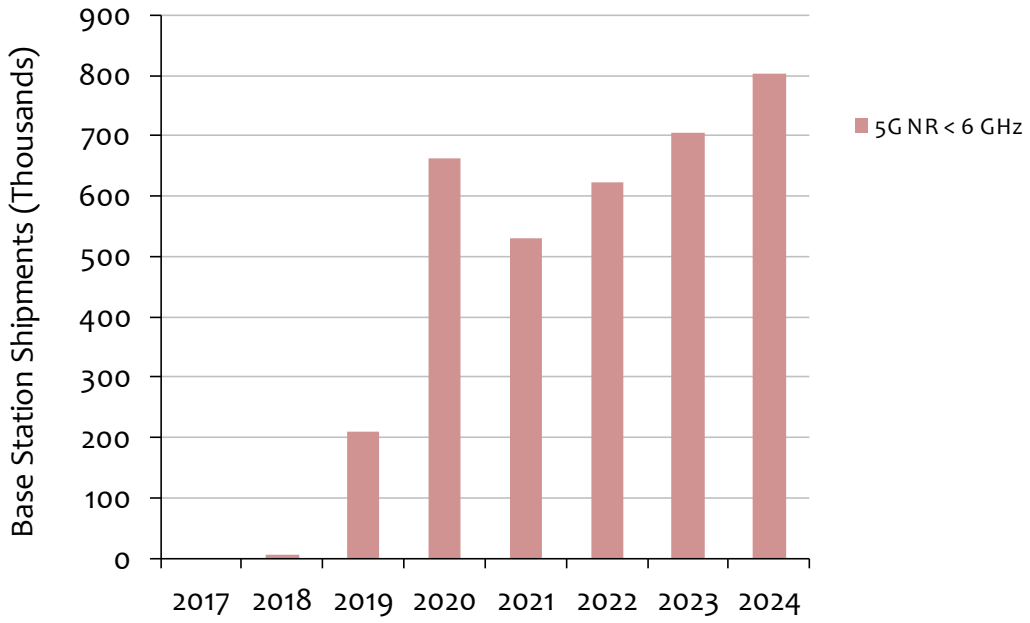
5G NR < 6 GHz

Mobile Experts has chosen to restrict ourselves to the bands below 6 GHz in our Macro Base Station forecast, because millimeter-wave gNodeB sites do not have the same characteristics as macro base stations (they're mounted on street-level poles, and only cover a small area).

China's three mobile operators are planning a huge deployment of 5G infrastructure in the 2.5 GHz, 3.5 GHz, and 4.8 GHz bands over the next three years or more. Although major uncertainties could dramatically change the forecast picture, currently we see a spike of deployment coming in 2019 and 2020 that will break all records for radio shipments.

In the rest of the world, 5G deployment will include significant numbers of base stations in Korea and Japan, as well as selected European and Middle Eastern countries. The United States will be limited by spectrum availability, with near-term 5G deployment concentrated at 600 MHz, 2.5 GHz and mm-wave bands. However, the USA is likely to make 5G spectrum available in the 3.7 GHz range in roughly 2021-2022.

Chart 10: 5G NR "Base Station" Shipments, 2017-2024



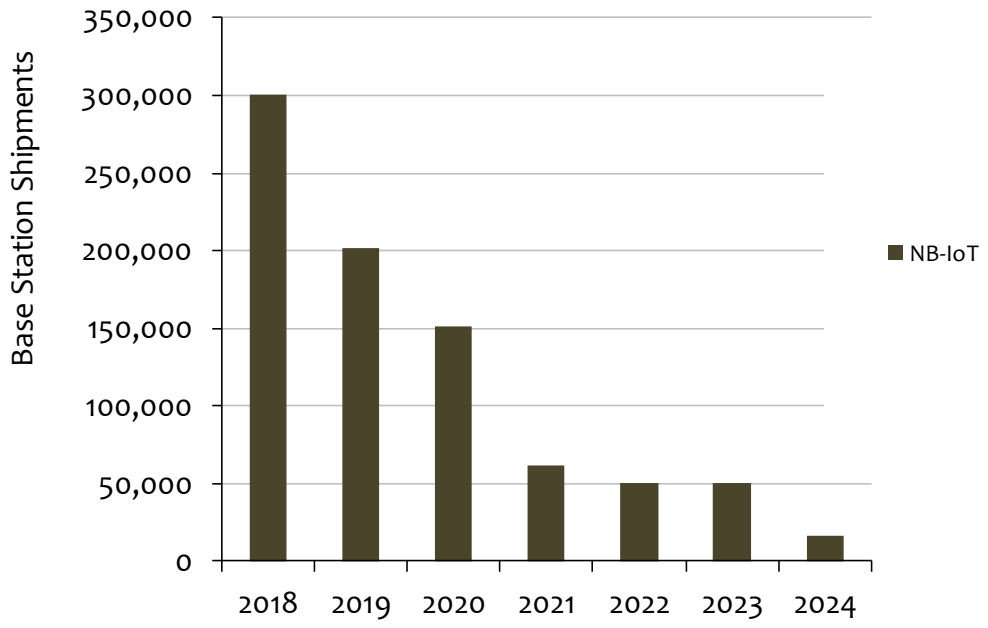
Source, Mobile Experts

NB-IoT

Most of the top 20 operators worldwide have 'modernized' their RAN over the past ten years, so they're ready for software upgrades to support LTE-M and NB-IoT. A few operators were not ready with older GSM equipment or other reasons for buying new hardware. The big deals are already done, as China is now mostly covered by new NB-IoT base stations. Dish will be deploying an NB-IoT network across the United States to fulfill legal requirements, but we expect them to minimize their investment by using a "tower and power" approach of high-power radios on the tallest towers possible.

We expect other examples like this to pop up in Latin America, Eastern Europe, and APAC where older GSM equipment is simply not capable of the NB-IoT waveform. Overall, the market for IoT RAN hardware will decline starting this year.

Chart 11: NB-IoT New Base Station Hardware Shipments, 2017-2024



Source, Mobile Experts

SECTION 2: TRANSCEIVER FORECAST

Mobile Experts always considers the RF transceiver to be our basic unit of measurement, since we track individual devices such as power amplifiers, filters, isolators, and similar components. This year, our transceiver numbers will explode with the rise of large numbers of Massive MIMO RUs, so we have been careful to track the individual operators driving the forecast and their plans for 64T, 32T, and 16T options.

Mobile Experts defines a transceiver as a single RF transmitter chain and its associated receiver chain(s), including the electronics from the ADC/DAC through the power amplifiers and duplexers that feed the antenna. With Massive MIMO, this means that the number of radio transceivers can get enormous very quickly.

We expect the surge of 5G deployment at 2.5 GHz and 3-5 GHz to be significant. China represents most of our forecast through 2022, due to strong government-led support for 5G deployment through all three mobile operators. Trial licenses have been issued to all three operators, and we expect "final" licenses in roughly June 2019. The reason for two steps in the licensing process is unclear, but we have heard that after 'final' licenses are issued, each operator will have 24 months to deploy 500,000 base stations each. Note: The Mobile Experts forecast has lower numbers than the Chinese Ministry of Industry and Information Technology (MIIT)is predicting, because of the possibility of network sharing between China Unicom and China Telecom, as well as possible delays.

Other countries will be deploying 5G more slowly, with 5G coverage overlaid on top of LTE in cities that have high traffic density. Still, we have tens of thousands of sites planned in Korea and Japan, driving more than 2 million transceivers in 2019 alone.

Mobile Experts breaks down the transceiver forecast in multiple dimensions:

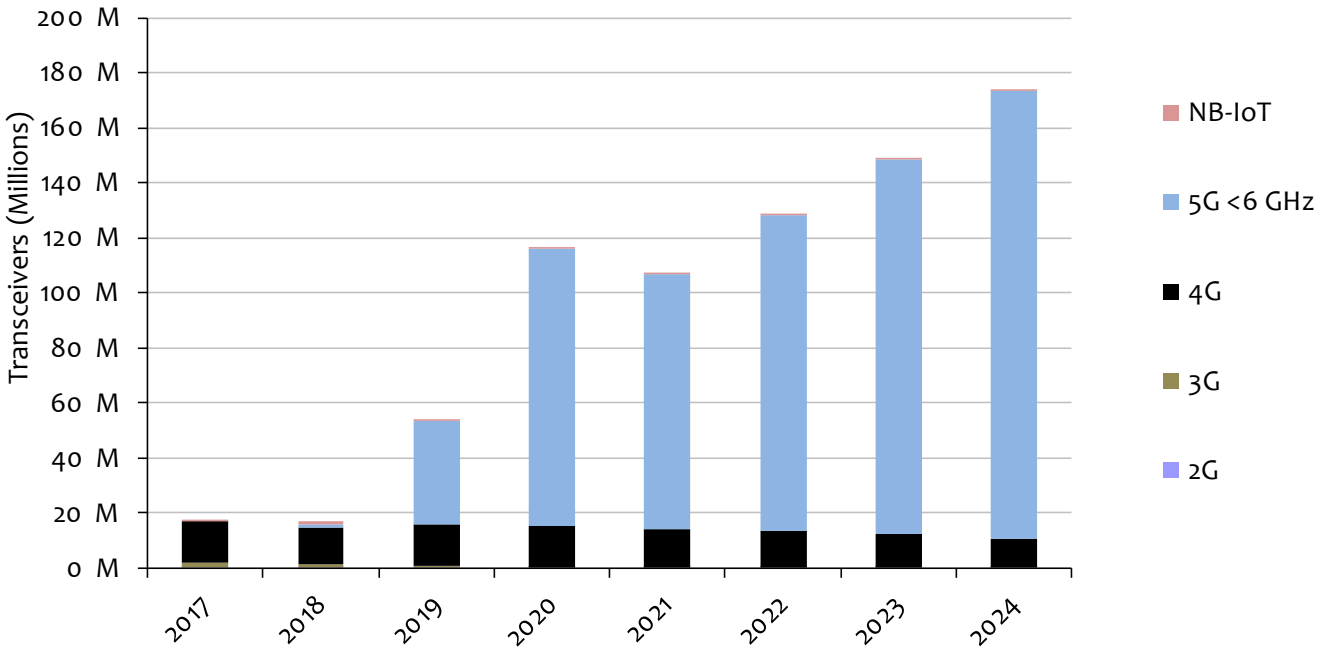
- Upgrades vs. New Deployment
- Breakdown by transceiver complexity (2T2R, 4T4R, through 128T128R)
- Number of Physical RRH units shipped
- Number of Active Antenna Systems and beamforming elements
- Breakdown by number of antenna beams
- Breakdown by number of MIMO streams
- Breakdown by RF power level
- Breakdown by region
- Market share by OEM

Transceiver Upgrades

Radios break down, so any mobile network needs spares and replacements to replace about 1% of the active network every year. Roughly 5% of transceiver shipments in 2018 were used as upgrades or replacements. Mobile Experts counts several types of radio shipments in the "upgrade" category, generally defined as a shipment of a new radio where the baseband processing is unchanged:

- Transceivers fail at about 0.5% to 1% per year, so new units are installed to replace failed units.
- MIMO upgrades require additional transceivers (2T2R to 4T4R means a new RRH deployment)
- Boosting the power level in a macrocell involves replacement of the RRH.
- An LTE channel deployed at 10 MHz may migrate to 20 MHz or wider, requiring new radio hardware to accommodate the wider channel. Intra-band Carrier Aggregation is a prime example of how a wider channel bandwidth would be required.
- Upgrade to Massive MIMO entails replacement of the RRH and antenna, to replace with an integrated antenna radio unit. Many of these upgrades in LTE systems are listed as new deployments because the BBUs are replaced.
- NB-IoT hardware deployments are not counted here because both RRH and BBU are impacted (this is not an upgrade but a new base station sale).

Chart 12: Transceiver Shipments, Upgrades vs. Virtual vs. New Units, 2017-2024



Source, Mobile Experts

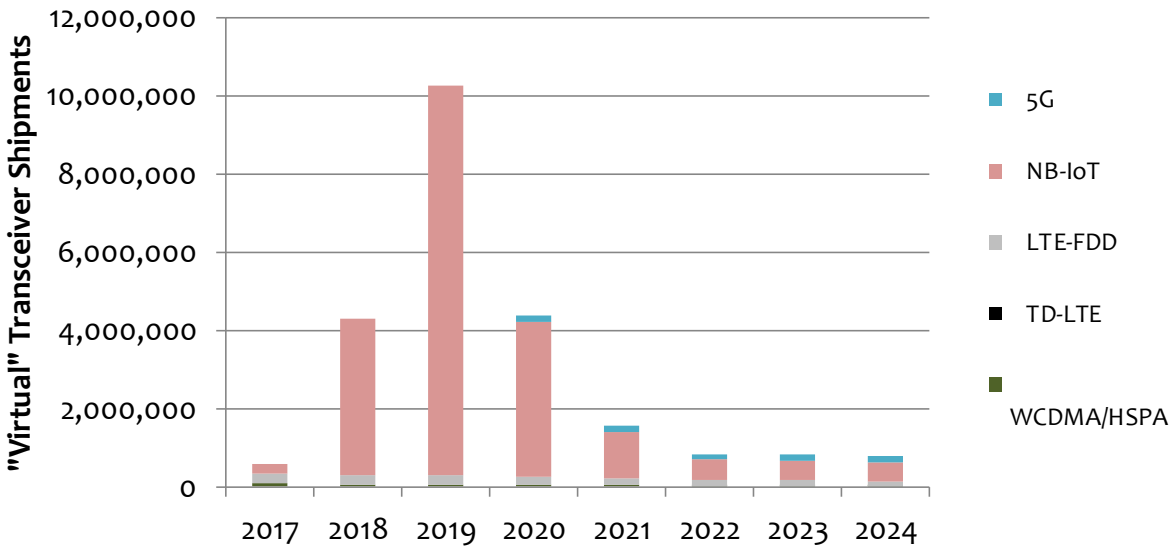
Software Upgrades: "Virtual" Transceiver Shipments

To keep accurate records, Mobile Experts records the number of "transceivers shipped" through software upgrades instead of physical transceiver units. Note that these units are NOT included in the other charts, so this category is shown for illustration only. (Note the large numbers of NB-IoT upgrades are via software)

In theory, the OEMs are selling hardware that is completely future-proof and all upgrades will be done through software. But this does not work out in the real world. Operators wind up buying new radio hardware for multiple reasons:

- Different frequency bands or wider bands are used for new network changes.
- The CPRI or OBSAI interface on the original equipment is too slow for a high-bandwidth LTE signal.
- The original 3G radio was deployed without MIMO transmitters, or the original 2T2R LTE deployment must be upgraded to 4T4R or higher.
- The base station platform has changed in form factor.
- The peak power of the waveform increases as we move from 3G to LTE to 5G NR, requiring new amplifier components.

Chart 13: "Virtual" Transceiver Shipments, by air interface, 2017-2024



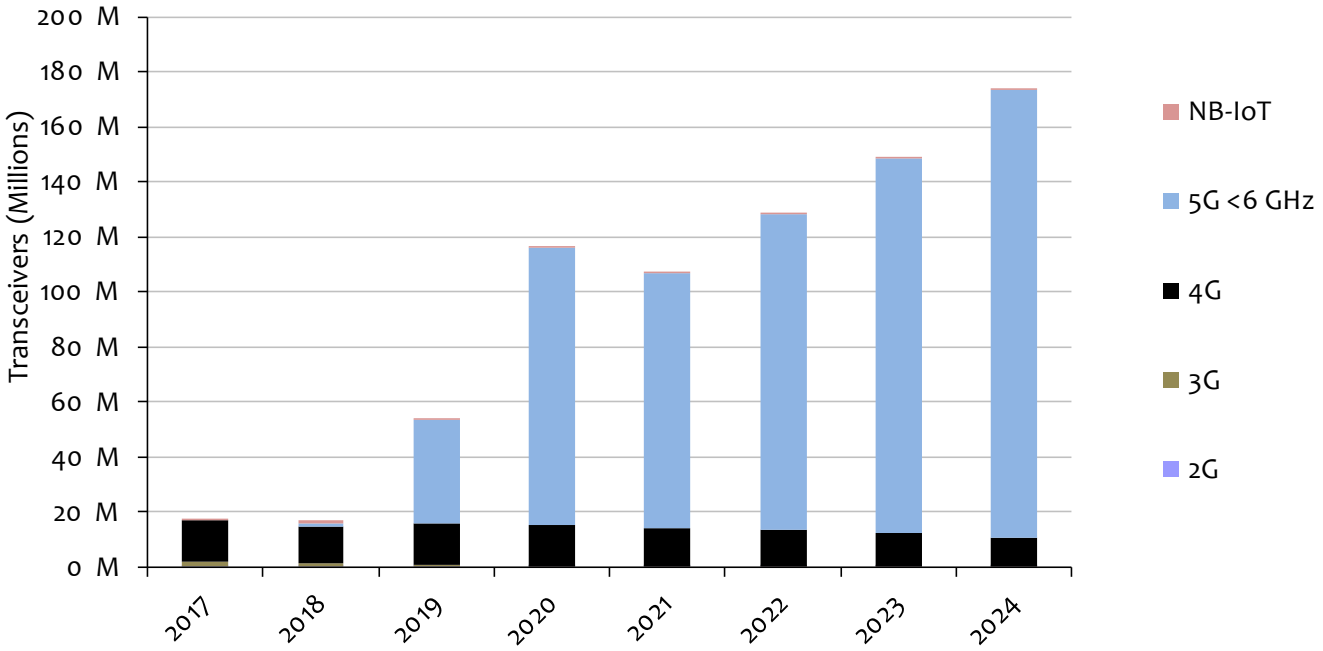
Source, Mobile Experts. Note: These units are NOT counted in Mobile Experts transceiver forecast totals.

Total Transceiver Shipment Forecast

The main story for 2019 is the rise of 5G, with huge numbers of low-power transceivers. LTE transceivers will also grow despite the general decline in RRH numbers, because massive MIMO in LTE will become a more significant part of the market. In both cases, 64T64R radio units are considered the 'baseline' configuration, but 16T and 32T options are also possible.

In total, the 5G surge in China will drive a spike in 2020, with a probable decline in 2021. In the longer term, we expect deployment in other countries to grow substantially, driving massive MIMO deployment to record numbers of transceivers in the 2022-2024 timeframe.

Chart 14: Transceiver Shipments, by generation, 2017-2024



Source, Mobile Experts

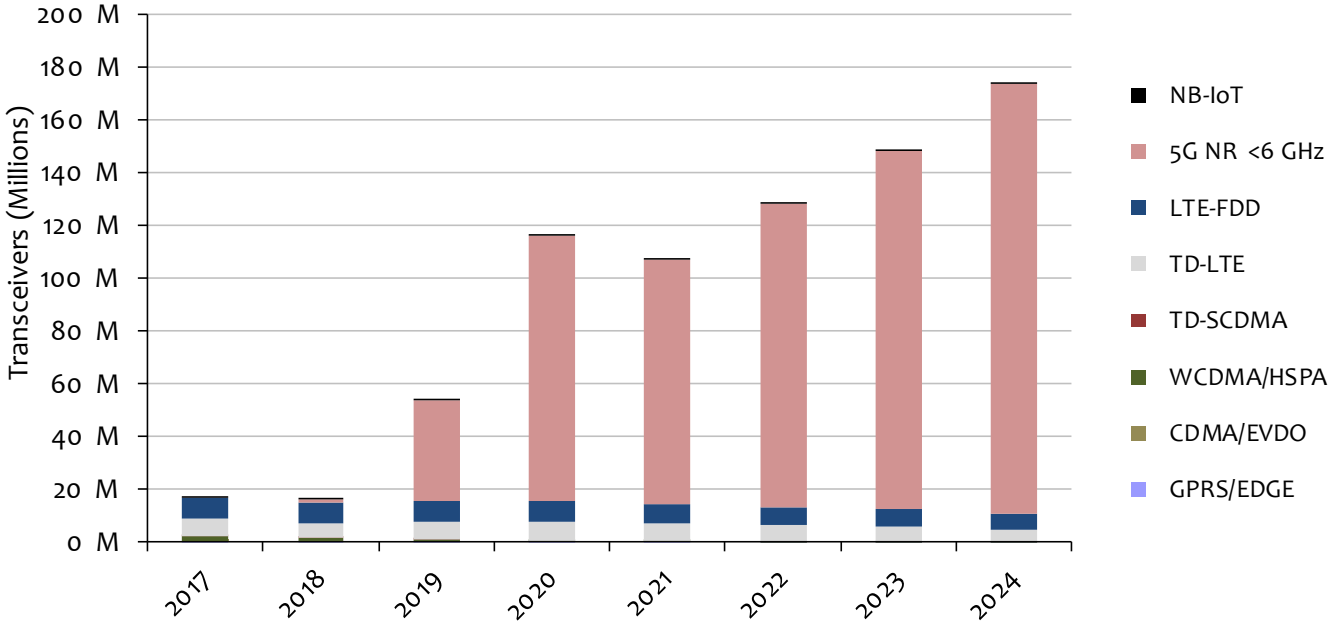
Breaking the market down by specific air interface, we see that 2G, 3G, and TD-LTE will be dropping away, but LTE-FDD will remain fairly flat. 5G is impossible to ignore, as the number of radio shipments will quickly jump into tens of millions.

FDD-based LTE is continuing along, gradually declining after 2018, essentially following the traditional slow decline that we've seen before for 2G/3G equipment.

Radio transceivers are expected to peak in 2018 due to the rise of 4T4R shipments (which effectively double the transceiver count for each base station shipped compared with the normal 2T2R configuration used in the 2015 timeframe).

GSM will continue at a low level through 2023 but we are seeing the end of CDMA and WCDMA.

Chart 15: Transceiver Shipments, by air interface, 2017-2024



Source, Mobile Experts

SECTION 3: Massive MIMO FORECAST

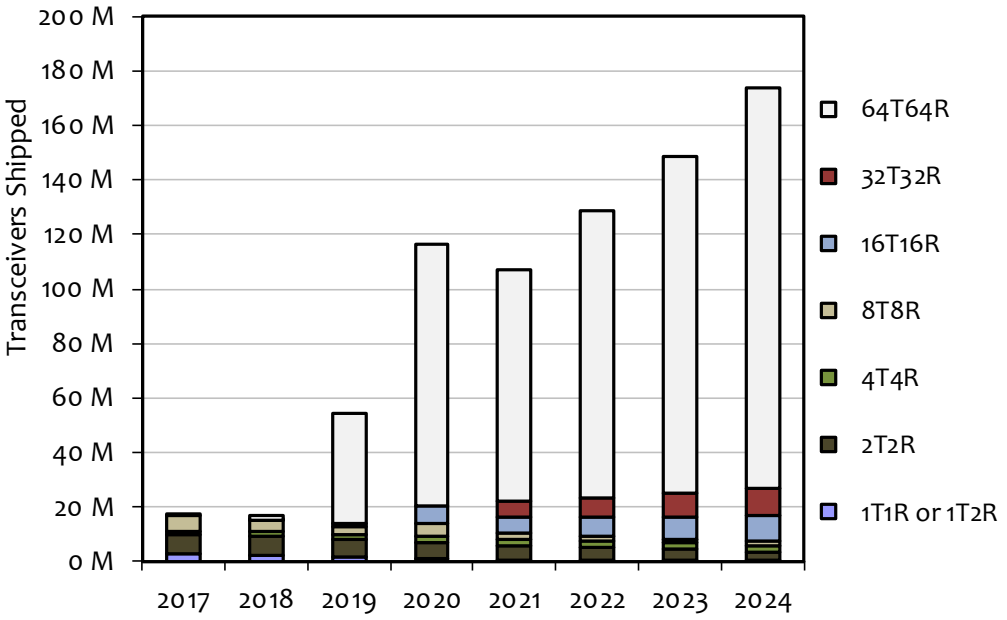
Massive MIMO is working well for TD-LTE operators now, so the technology is proven and many operators are placing their bets on Massive MIMO for densification. One important distinction in the trials comes from the raw physics of antennas: For FDD bands (especially below 1 GHz) the size of a 64T64R array is huge, so very few large Massive MIMO systems will be deployed in those bands. Cost, weight, wind load, and power all contribute to making it unprofitable. However, in TDD bands above 2.3 Ghz the antenna size will be reasonable, and the benefit is larger due to the wider bandwidth of the channels. So we expect a concentration of Massive MIMO deployment in TDD bands above 2.3 GHz for the next four years.

5G will be deployed in both FDD and TDD bands, but most 5G will be in TDD and will use Massive MIMO extensively.

Overall, we note several trends for each level of product complexity:

- The SISO category (with either 1T1R or 1T2R radios) is becoming dominated by NB-IoT deployment, with very small numbers in the leftover 2G/3G market.
- 2T2R is declining, as most new deployment for LTE-FDD is 4T4R.
- The 4T4R market will be focused in FDD bands. There is a possibility that 5G NR will be deployed in TDD bands in a 4T4R configuration, but guidance from China is that their networks will be 8T8R as a baseline configuration, to match the CMCC LTE network.
- Either 16T16R or 32T32R will be used in some cases for 5G NR deployment. We have conflicting signals about the use of each level, either for urban FDD systems or for suburban/rural TDD systems. In the end, we believe that OEMs will be able to control how many configurations they will support, and steer their customers into one of these two options.
- The 64T level will be a common configuration for urban 5G NR deployment as well as the TD-LTE upgrades over the next few years. We have heard some complaints from Chinese operators about the cost, weight, and wind profile of these antenna systems, so we have moved some of our forecast toward 32T and 16T options.
- We're tracking even higher levels of massive MIMO in mm-wave systems, but below 6 GHz we believe that 64T will be the high end through 2023 at least.

Chart 16: Transceiver Shipments, by Massive MIMO level, 2017-2024



Source, Mobile Experts

SECTION 4: REMOTE RADIO HEAD (RRH) or RADIO UNIT (RU) FORECAST

RRH Architecture

LTE base stations have been built using a "Remote Radio Head" (RRH or RRU) architecture for many years, and in most cases the OEMs have adopted CPRI as an interface for serialized I/Q data between the radio head and the baseband processing. Over the past few years, baseband processing has migrated to a centralized pool for efficiency, but the basic architecture has not changed.

The architecture is now changing, and in a rough way the new architecture will coincide with the arrival of 5G. Instead of a RRH with a CPRI interface, the OEMs are all moving toward a split of baseband processing, with real-time baseband processing (PHY and some MAC functions) in the Radio Unit, and other baseband processing in the Distributed Unit (DU).

Note that in this forecast, Mobile Experts refers to RRH for LTE and RU for 5G.

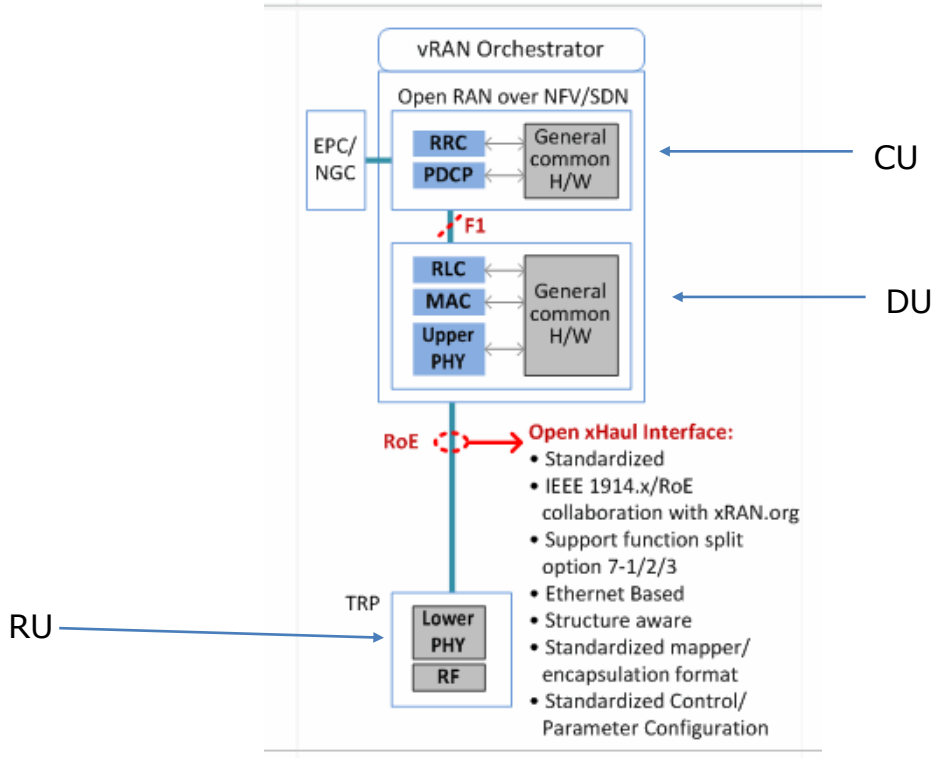


Figure 2. Diagram for CU/DU/RU architecture

Source: IEEE 1914

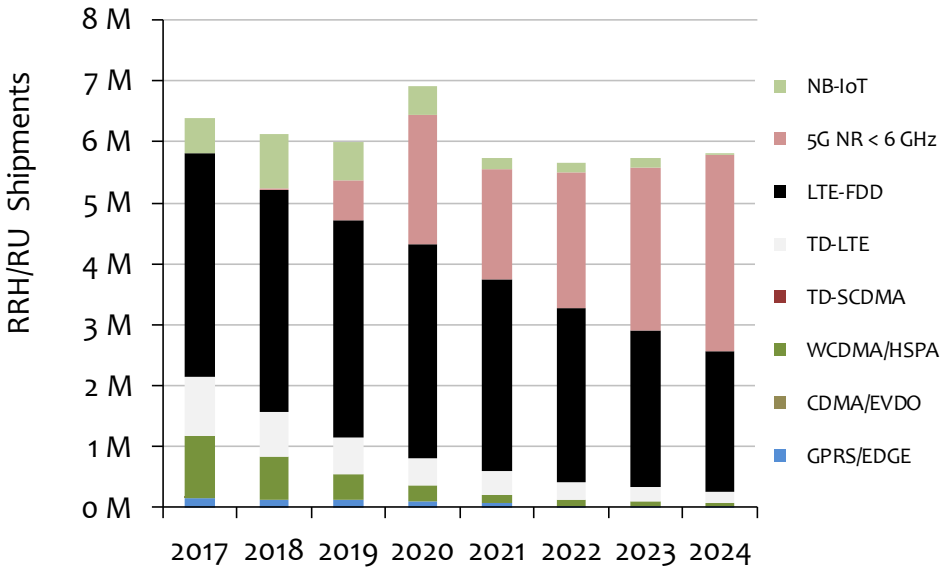
Note that Mobile Experts defines a macro RRH as a unit with 40W composite power or greater, and used below 6 GHz. Lower power remote radio heads are available, and in fact many have been shipped into Asian markets. Mobile Experts tracks these lower power units in our SMALLCELLS forecast. Millimeter wave RRH units are tracked in our 5GMMWAVE forecast.

RRH/RU Forecast

Most people assume that each "base station" includes three RRH/RU units, but in fact with a centralized RAN architecture the number is closer to 4.2 for LTE today. In other words, each baseband processing unit supports an average of 4.2 RRH units in the field.

For this reason, Mobile Experts rebuilt our forecast model to use RRH or RU units as our primary model input. We calculate base stations as a way to estimate the level of capacity available, but our primary forecast is based on the number of radio units.

Chart 17: Physical Macro RRH Shipments, by air interface, 2017-2024



Source, Mobile Experts

During 2018, the number of RRH units shrank again in 2G, 3G, and 4G, as expected in the decline of 4G deployment. Strong NB-IoT base station shipments in 2018 offset the decline to some degree.

For 2019, there are multiple new factors which contribute to strong RRH deployment:

- China Mobile will begin deployment of large numbers of units at 2.5 GHz in China. We expect roughly 450,000 RU units in 2019 for this one customer.
- Korean operators will begin deployment of 5G at 3.5 GHz with about 10,000 RU units each.
- FirstNet deployment in the USA is ongoing with multi-band RRH units.

- T-Mobile USA has begun an aggressive deployment of 600 MHz FDD base stations (using LTE now, but hopefully upgradeable to 5G NR when the standards are ready)
- Ongoing LTE capacity deployment continues in almost every LTE network, with second/third/fourth frequency bands built out to add capacity to existing LTE coverage worldwide.

Important notes:

- 5G RU units will generally consist of Integrated Antenna Radio units, including multiple radio paths and the associated antenna elements.
- TD-LTE RRH units will use Massive MIMO and IAR construction in some cases but we believe this will be limited to about 10% of ongoing TD-LTE deployment.
- NB-IoT upgrades are counted in the Mobile Experts forecast only if a radio hardware upgrade is required. Most NB-IoT deployment will be possible with software upgrades, so the small numbers of RRH units shown here represent the physically upgraded units.

SECTION 5: AAS and IAR: Beamforming and MU-MIMO

Confusion reigns in the market when people discuss active antenna systems and Multi-User MIMO. To clarify things, this forecast tracks multiple items as independent variables:

Active antenna systems refer to arrays of antennas that are actively steered. An AAS is not necessary an integrated unit with radio electronics in the same enclosure, and in fact the early implementation of TD-LTE did not include integration despite eight separate steerable antenna elements. The number of antennas in the array can vary from 8 to 256, independent of the number of transceivers in the radio.

Integrated Antenna Radio (IAR) refers to the physical architecture of the radio unit. An IAR is defined as a single enclosure that includes both antenna elements and active radio electronics.

The number of transceivers and their configuration is determined by the number of DACs/ADCs. Each DAC converts a single I/Q signal to RF

Beamforming refers to the ability to shape a beam and steer it. Basic physics constrains the system, so that the number of beams is typically less than ¼ the number of antenna elements in the array. The number of beams correlates directly with the number of steering elements (either analog or digital) in the radio system.

The number of Multi-User MIMO streams is the main metric for the level of capacity in the radio system. The number of streams comes from the number of unique baseband processing data flows… each baseband data stream can feed to multiple DACs, passing through even higher numbers of steering elements, PAs, and antennas.

Integrated Antenna Radio shipments

At the simplest level, the Integrated Antenna Radio configuration involves the physical integration of the antenna and the RRH electronics, regardless of whether a beamsteering array is used. This concept has been used by Ericsson with customers such as T-Mobile, SMART, and a few other operators in the FDD market, without any active steering. More recent implementation of 5G radios are almost all implemented as IAR.

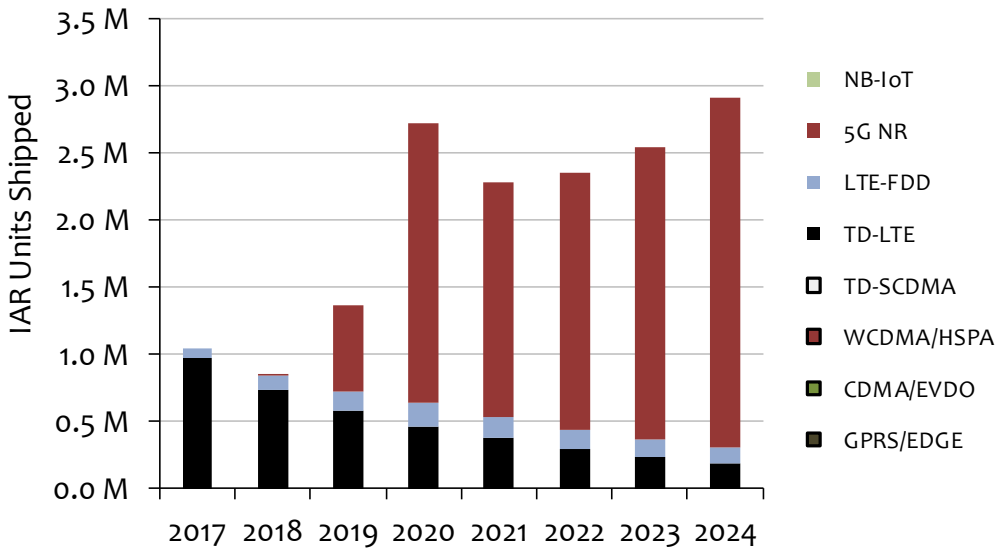
In the FDD market, IAR products have not been very popular, because the flexibility of the solution makes it impossible to upgrade the IAR for additional bands or

different power levels. The weight and size of the antenna can be challenging for the field technicians.

Ericsson has modified their AIR product to include "field replaceable units" that plug into the antenna chassis with blind-mate connectors. This change is a big improvement, because it allows for smaller size/weight in each physical unit, and it allows for upgrade of the hardware in the future without taking down the entire assembly.

For 5G radios, all massive MIMO radios will be integrated with antennas in order to reduce losses and for simple practical considerations (imagine trying to connect 64 cables at the top of a tower in the rain, without making a mistake). Future development will focus on multi-band RUs with integration of wideband radios and antenna systems covering multiple 5G and/or LTE bands.

Chart 18: Integrated Antenna Radio Shipments, by air interface, 2017-2024



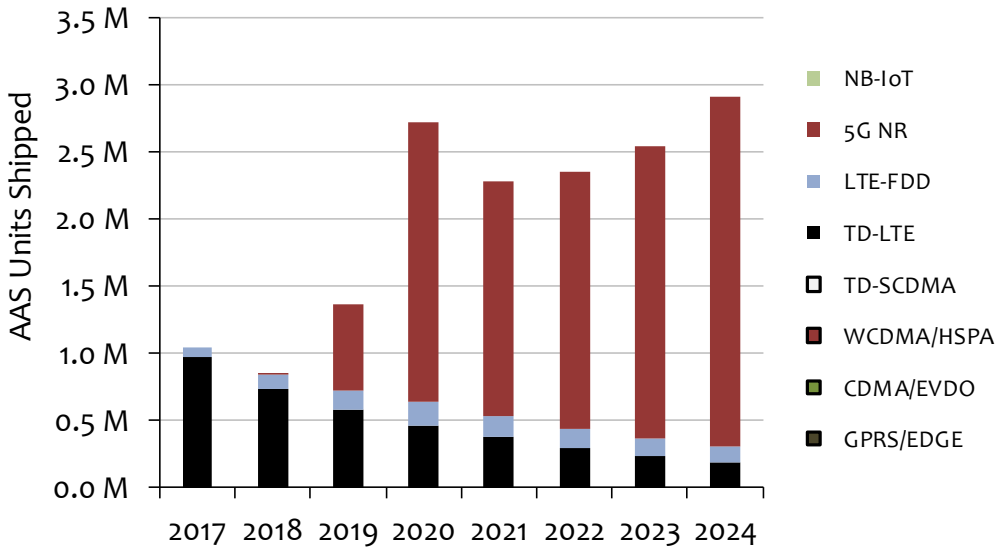
Source, Mobile Experts

AAS Transceiver shipments

TD-LTE deployment drove AAS architectures into the mainstream, especially with huge Chinese deployment in the 2014-2015 timerame. But in fact the steering on those early deployments was limited, and the Chinese operators have upgraded some sites with improved steering via software upgrade during the past four years. These simpler implementations at 8T8R are now moving up to 64T64R and higher, for both TD-LTE and 5G NR.

The higher complexity allows for tighter beams, and also for higher isolation between beams to improve the overall spectral efficiency. One tradeoff is that with many small power amplifiers, the total heat load of a large array can be higher than a simpler 4T4R radio head with four big amplifiers. This issue can be resolved by using the higher gain of the antenna to turn down the power.

Chart 19: RRH Units shipped in AAS configuration, by air interface, 2017-2024



Source, Mobile Experts

The capacity benefits of 5G depend primarily on the use of active antenna arrays. In fact, without AAS, a 5G radio would only have about 10-15% higher capacity than an equivalent LTE radio. So we expect all 5G deployment above 2.3 GHz to implement AAS. Lower bands will not use AAS to the same level because arrays of antennas can become very large in lower bands. We expect to see a few FDD bands (1800, possibly 1900 MHz) implementing AAS, but the 600-900 MHz bands are likely to remain with simpler 4T4R non-steered radios.

MU-MIMO: Beams and Streams

The capacity benefits of Multi-User MIMO come from re-using the same spectrum in different antenna beams. It's important to achieve high isolation between the beams to prevent interference between the two signals. For this reason, the number of beams in MU-MIMO is typically arranged at less than ¼ the number of antennas in

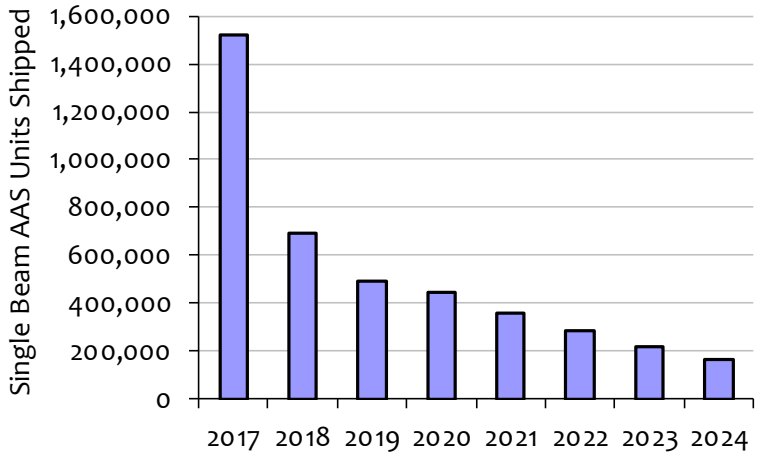
the array. This allows for enough definition of the beam to minimize the spatial crossover between the beams.

The number of streams is generally 2 or 4 streams per beam. So, if a 64T64R radio unit has 8 beams, each beam can include 2x2 MIMO for a total of 16 streams.

Note: The Mobile Experts macrocell forecast is based on the adoption of MIMO technology in the downlink only. Separate forecasts illustrate the slower adoption of MIMO technology in the uplink, where handset battery limitations are a major factor. For simplicity in our infrastructure forecast, we remain focused on downlink MIMO streams.

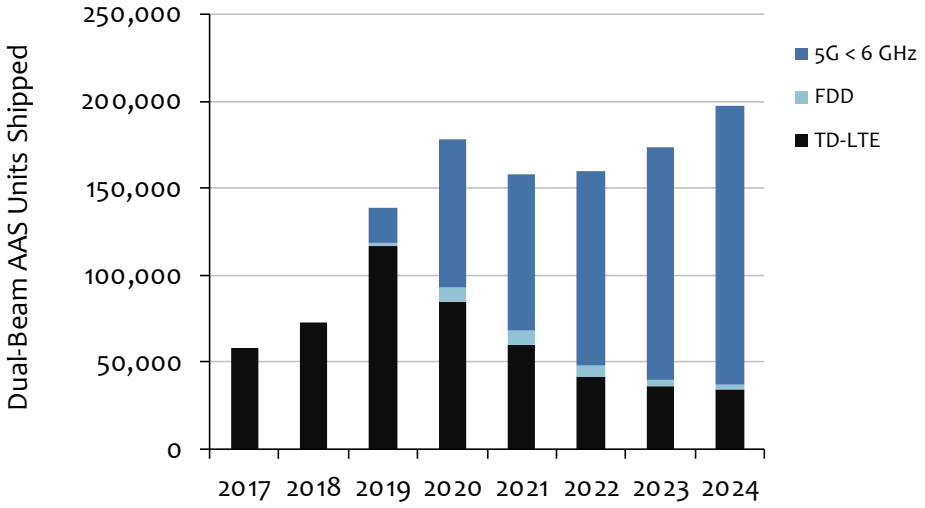
The following charts are shown as a forecast of the number of transceivers in each beamsteering configuration. For the purposes of base stations below 6 GHz, this generally indicates the level of complexity for the digital beamsteering processor function.

Chart 20: Forecasted Single Beam AAS Shipments, 2017-2024



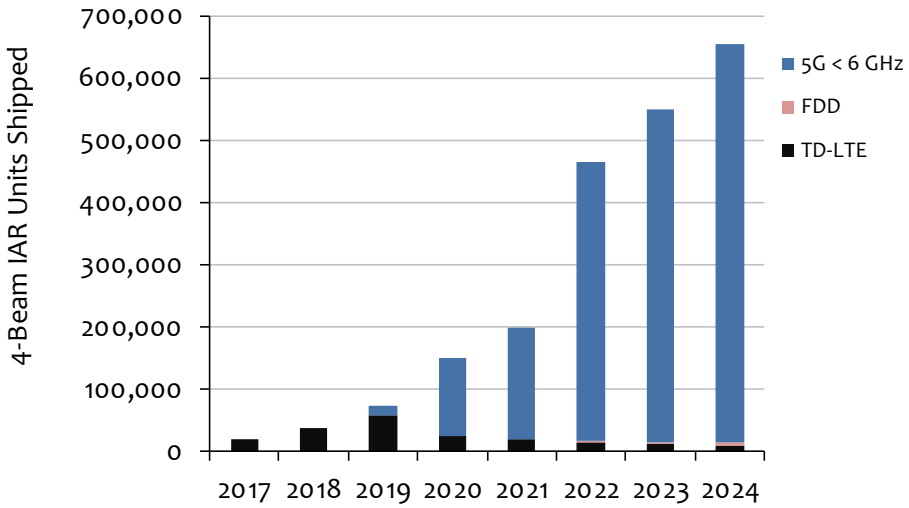
Source, Mobile Experts

Chart 21: Forecasted 2-beam AAS Shipments, by air interface, 2017-2024



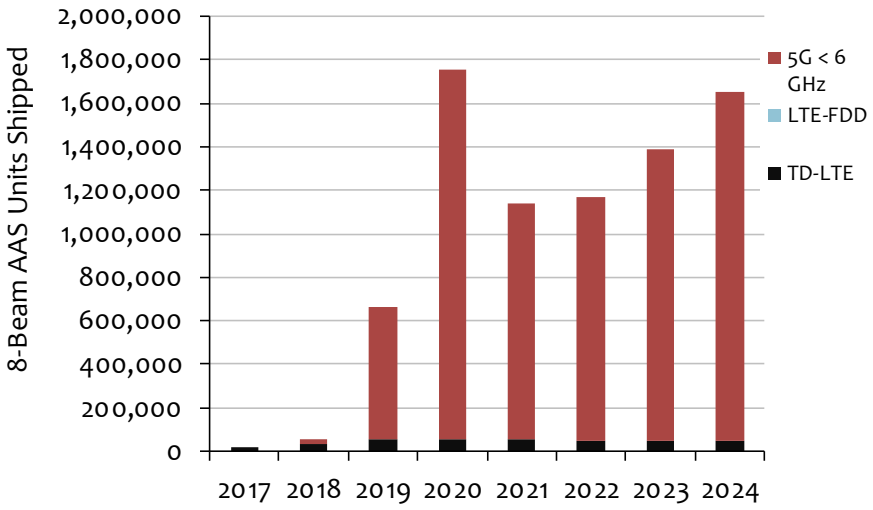
Source, Mobile Experts

Chart 22: Forecasted 4-beam AAS Shipments, by air interface, 2017-2024



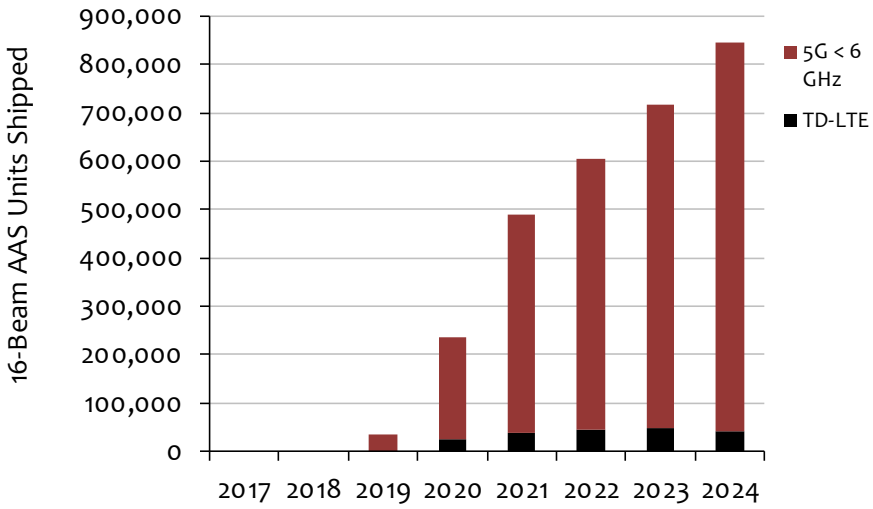
Source, Mobile Experts

Chart 23: Forecasted 8-beam AAS Shipments, by air interface, 2017-2024



Source, Mobile Experts

Chart 24: Forecasted 16-beam AAS Shipments, by air interface, 2017-2024



Source, Mobile Experts

SECTION 6: TRANSCEIVER FORECAST BY POWER LEVEL

The clear trend is toward larger numbers of transceivers, with lower power in each radio chain. However, that simple conclusion is complicated by the need for FDD systems at high power, including new 5G deployments below 1 GHz and other cases that run counter to the trend.

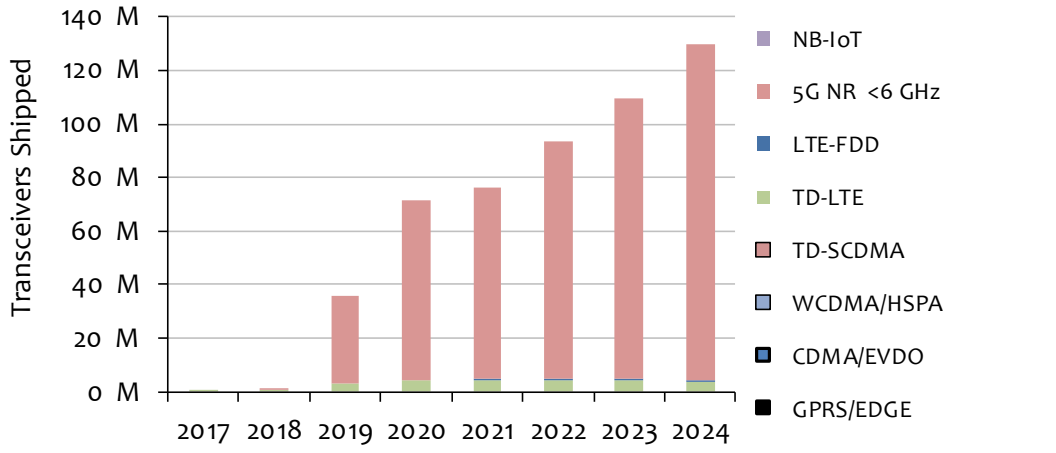
Mobile Experts defines a macrocell as a mobile infrastructure site in which a radio sector transmits a composite rated power of 40W or more. In each sector, the total power of all diversity transmitters, MIMO transceivers and/or all AAS transceivers is calculated to determine the composite power. Systems with composite power between 5W and 29W in a sector are categorized as "microcells" and are not included in the scope of this forecast. To be clear, a 5G antenna array with 64 elements that transmits 60W of composite power (1W per element) is considered a macro system.

Very Low Power Transceivers (below 5W)

The 64T configuration is becoming the industry's most common RU type, and we expect a major surge of shipments this year China's 5G deployment gets going. Massive MIMO systems with high numbers of transceivers (64T64R) generally use individual transceiver RF power below 5W. Note that we also count 32T radios in this category, because the current baseline for 32T systems involves an output power of about 4-5W per radio. (in the future these shipments may move into the 5-19W category if power is increased).

In China, shipments have already begun for some long-lead components (as of January 2019). Over this first year of deployment, we anticipate that 64T will represent about 85% of 5G deployment… but over time we expect 16T and 32T configuraitons to take a more prominent role. The primary reason is that we believe the 5G deployment will migrate from the city center to the suburbs and even rural areas as the deployment continues.

Chart 25: Transceiver Shipments, Below 5W rated power, 2017-2024

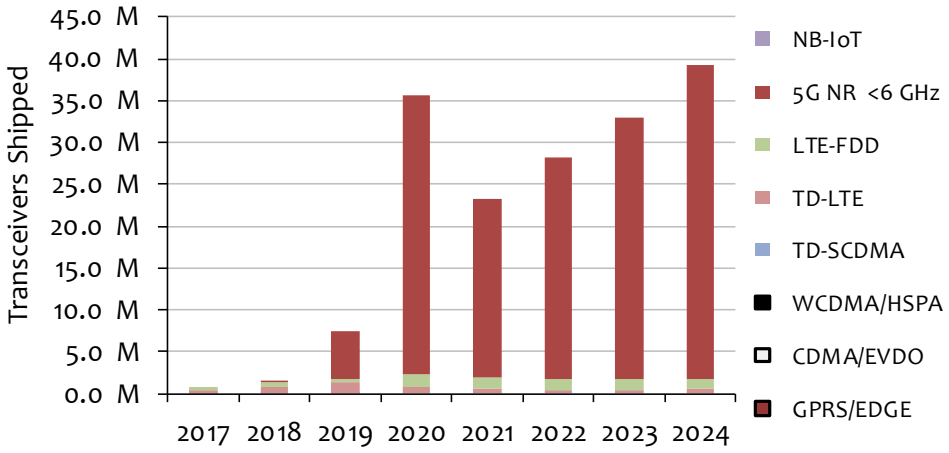


Source: Mobile Experts. Includes macro only (Base stations with greater than 40W composite power per sector)

Low Power Transceivers (5-19W)

Radios in 8T through 16T configurations fall into this power level category. In China, we're predicting that about 20% of the 5G network will use a 16T16R configuration, with another small percentage using an 8T configuration. This estimate is very uncertain at this time, as there still remains a strong likelihood of changes in the proportions of 8T through 64T configurations.

Chart 26: Transceiver Shipments, 5-19W rated power, 2017-2024



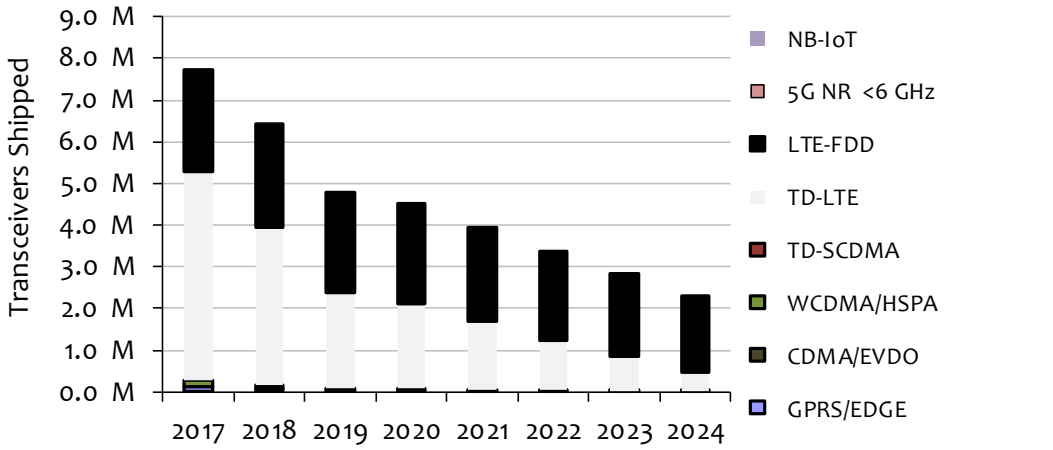
Source: Mobile Experts. Includes macro only (Base stations with greater than 40W composite power per sector)

Transceivers rated at 20-39W

Some 4T4R FDD base stations and simpler TDD units with 4-8 transmitters will use power levels between 20-40W. However, we expect the TDD market to migrate quickly to 5G investment, so the number of base stations using an 8x25W configuration are likely to drop over the next few years.

Generally speaking, this 'moderately high' power level is a smaller segment of the market because operators either use four big transmitters or 64 small ones.

Chart 27: Transceiver Shipments at 20-40W rated power, 2017-2024



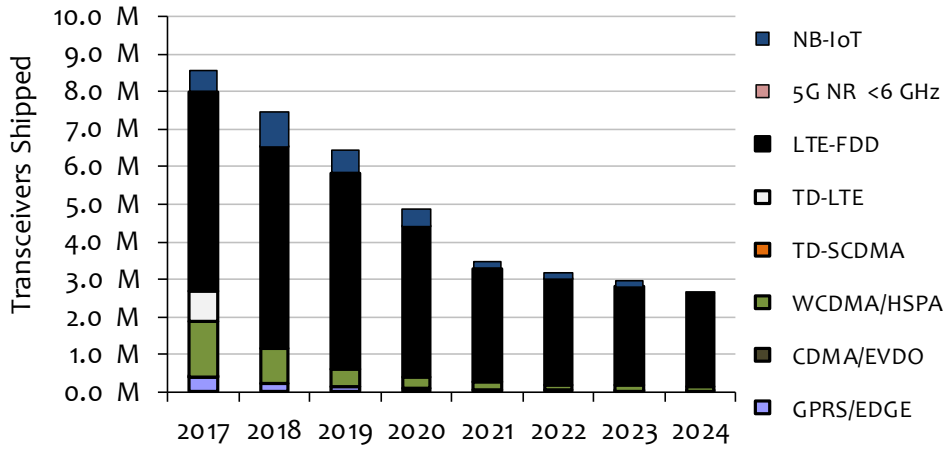
Source: Mobile Experts

Transceivers 40W and above

We still see plenty of systems with 4x40W, 2x60W or 2x80W shipping for LTE in the FDD bands. In cases where Massive MIMO will not be used, this is still the best configuration for large-area coverage from a tall tower.

The IoT market has also contributed in this market, and will continue with DISH deploying some NB-IoT infrastructure. In the big-picture view of the market, however, the IoT segement small in terms of volume and revenue.

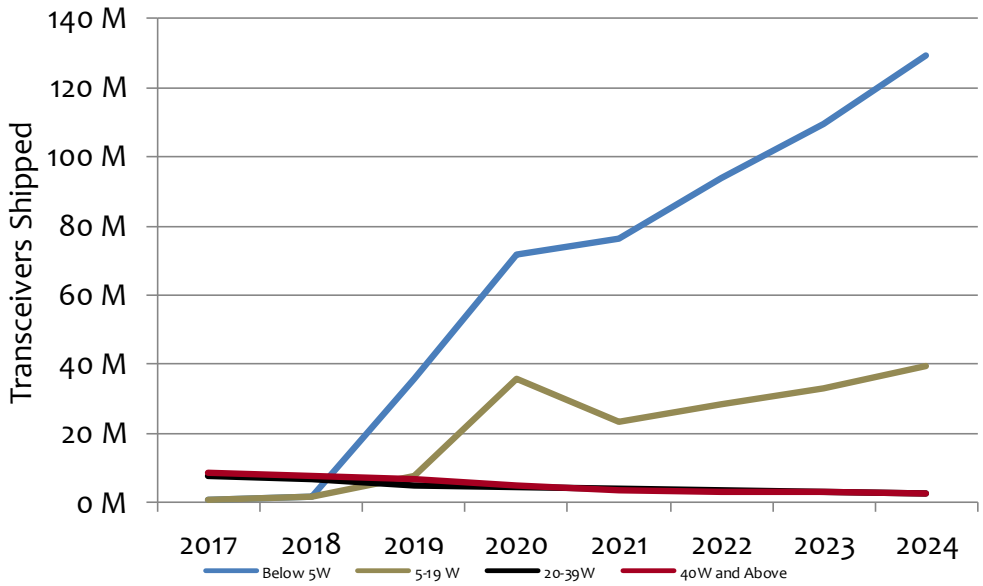
Chart 28: Transceiver Shipments above 40W rated power, 2017-2024



Source: Mobile Experts

Clearly the low-power transceivers are shooting upward in terms of the hardware shipped over the next few years. The segments with higher power are still there, and revenue is significant for power-dependent devices such as power amplifiers and isolators….but the sheer number of shipments in the low power categories are tilting the market toward a very different profile.

Chart 29: Transceiver Shipments by rated power level, 2017-2024



Source: Mobile Experts

SECTION 7: TRANSCEIVER SHIPMENTS BY REGION

This year, the balance of shipments between different regions will swing decidedly toward China. LTE deployment in most world regions remains on the downslide, as the peak deployment has already happened but ongoing capacity upgrades are taking place.

We break down the regional view of transceiver shipments according to air interface, so we can see that the swing will be completely based on 5G, while 2G, 3G, and LTE shipments will remain more balanced.

Chart 30: Transceiver Shipments, by Region, 2017-2024

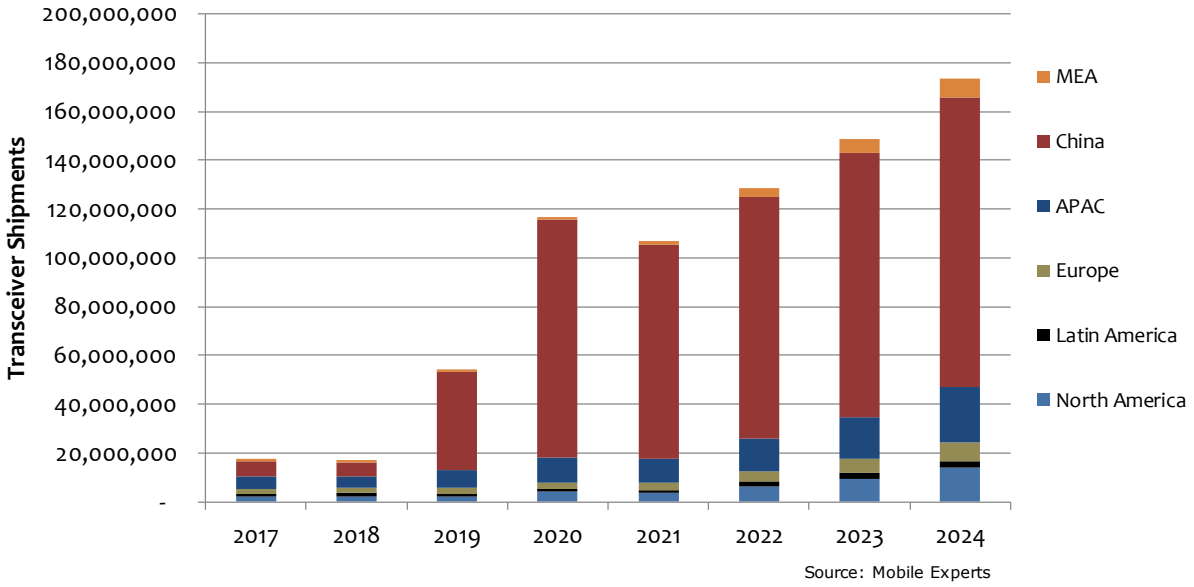
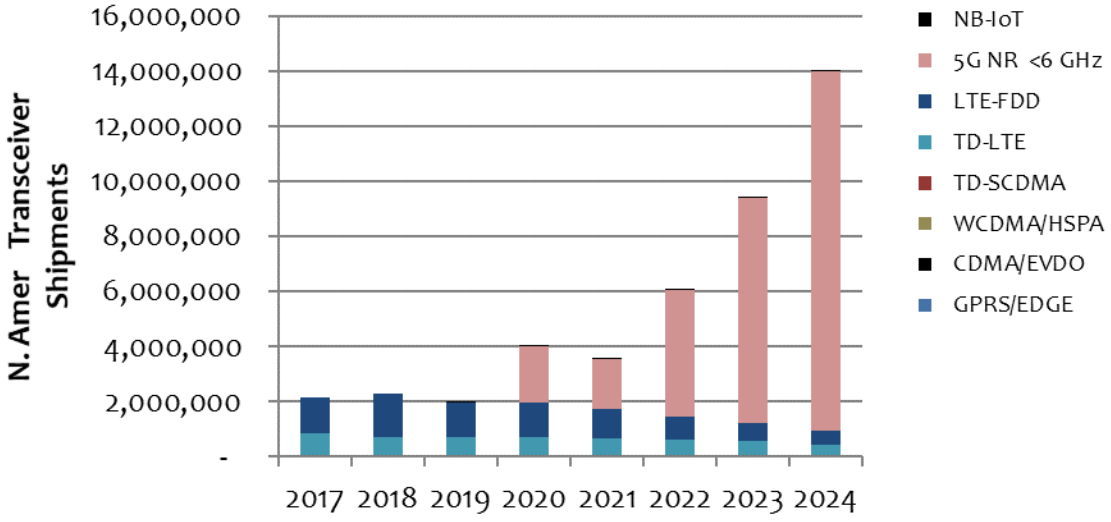
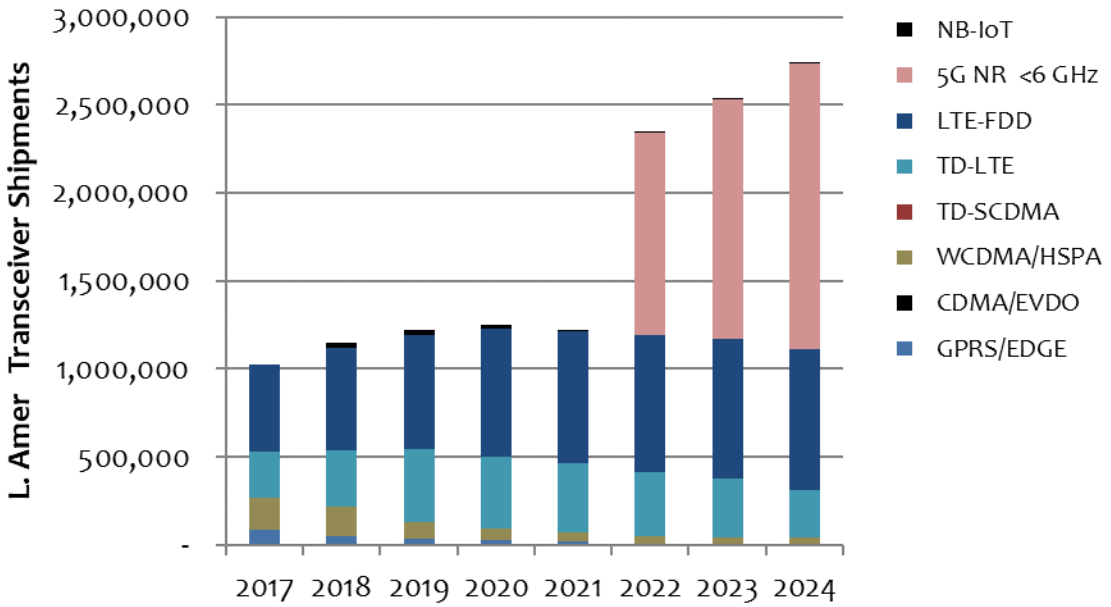


Chart 31: Transceiver Shipments, North America, by air interface, 2017-2024



Source: Mobile Experts

Chart 32: Transceiver Shipments, Latin America, by air interface, 2017-2024



Source: Mobile Experts

Chart 33: Transceiver Shipments, Europe, by air interface, 2017-2024

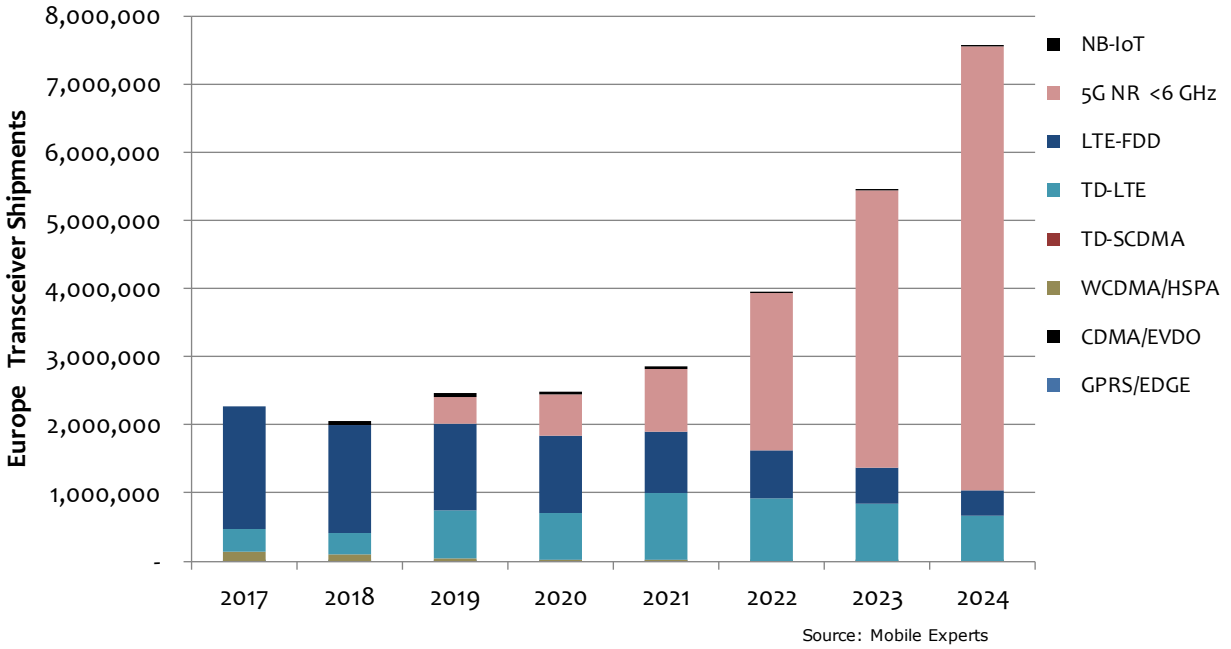
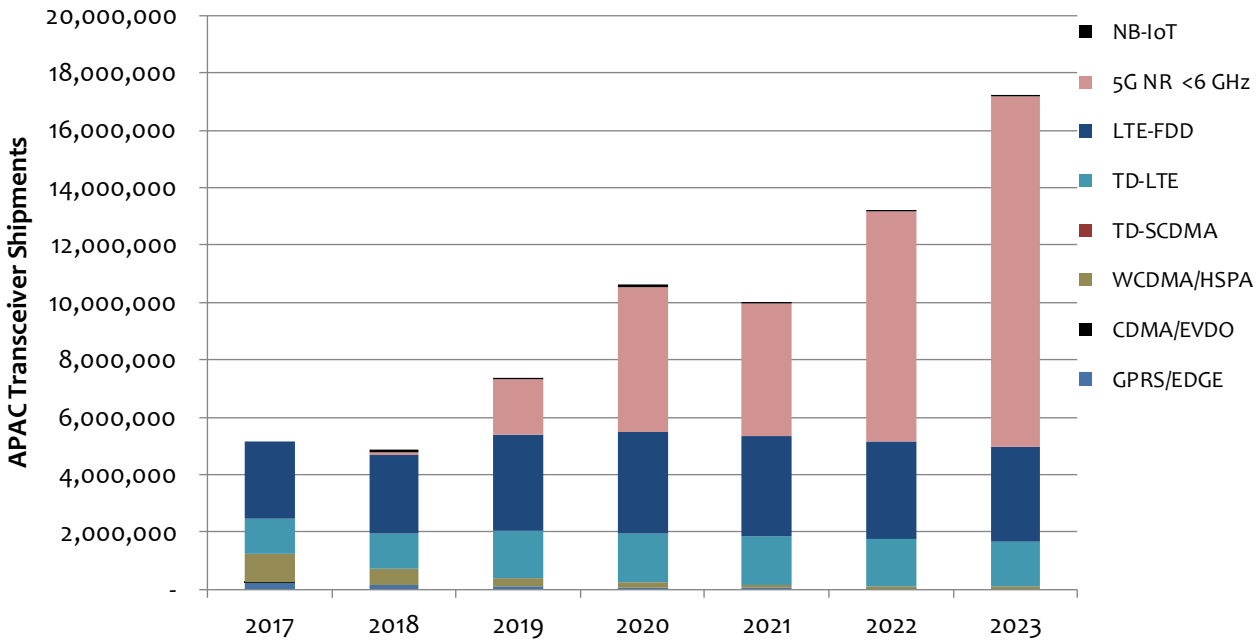


Chart 34: Transceiver Shipments, APAC, by air interface, 2017-2024



Source: Mobile Experts

Chart 35: Transceiver Shipments, China, by air interface, 2017-2024

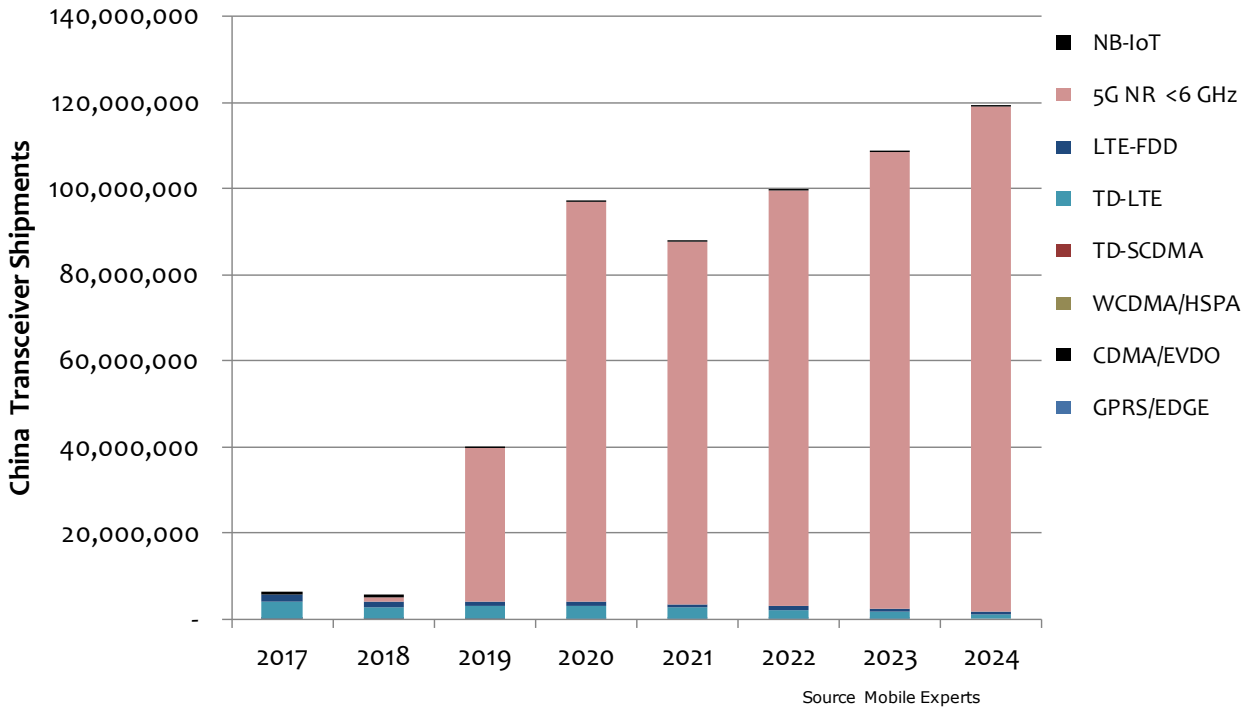
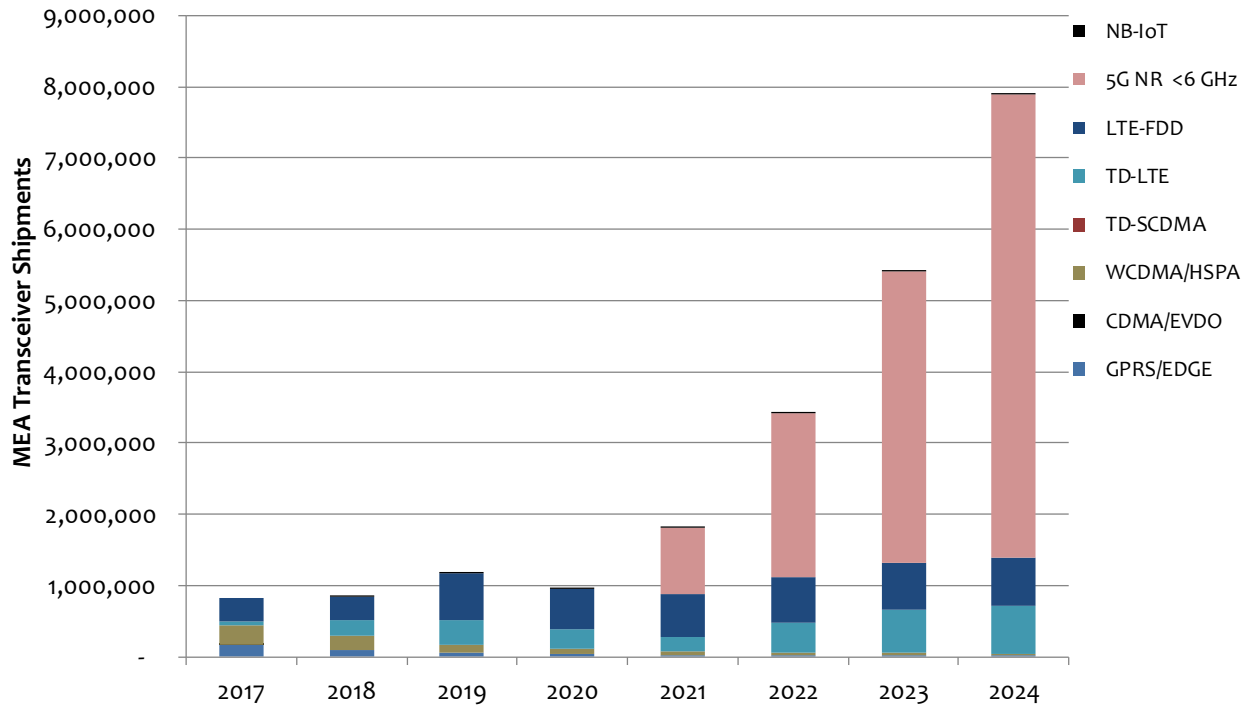


Chart 36: Transceiver Shipments, MEA, by air interface, 2017-2024



Source, Mobile Experts

SECTION 8: SHARE OF GLOBAL SHIPMENTS BY OEM

Competition has changed between the four top OEMs. In the past, Huawei and ZTE grabbed market share with extremely low prices, essentially giving base stations away. Today, their pricing has stabilized at more reasonable levels, but they are locked out of many markets for political reasons.

Meanwhile, upstarts such as Samsung and Airspan are getting some traction, breaking in to the market. In some ways, the political fight over Chinese OEM access to markets creates the perfect environment for Samsung and AIrspan to succeed. Because American and allied countries won't accept Chinese vendors, Samsung is the natural pick to bring competition to a market that otherwise would be too comfortable for a duopoly.

Methodology for estimating shares

Shipment shares are estimated based on the contract awards announced and by public financial disclosures by each of the major OEMs. These figures were double-checked against shipment data for key components.

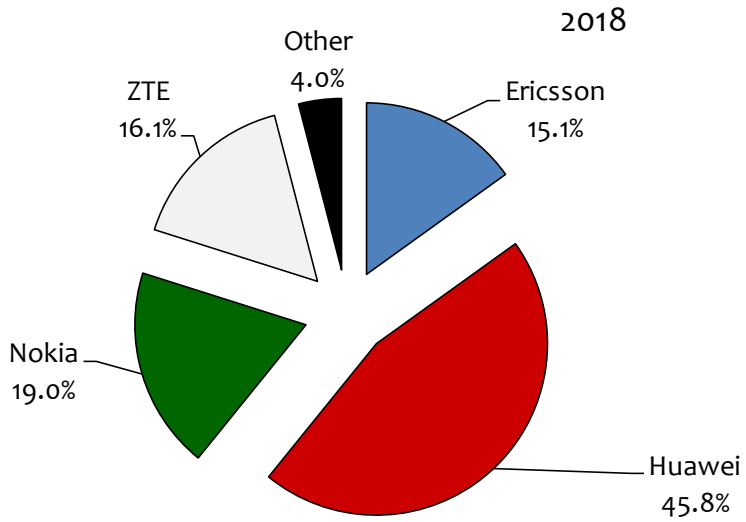
Important note: Mobile Experts does not track traditional "market share" for the base station market. Most analysts include base station site hardware and software revenue, as well as service revenue in many cases. The result is not meaningful to the hardware supply chain.

The Mobile Experts forecast does NOT address revenue share. Instead, the Mobile Experts forecast focuses simply on the share of RF transceivers shipped by each vendor, in order to best estimate the market for semiconductor suppliers. Revenue for the transceivers is not considered because the "pricing" of a transceiver is arbitrary. The below estimates reflect the number of transceivers shipped in order to most directly relate to the component market.

Market Share Charts by Air Interface Standard

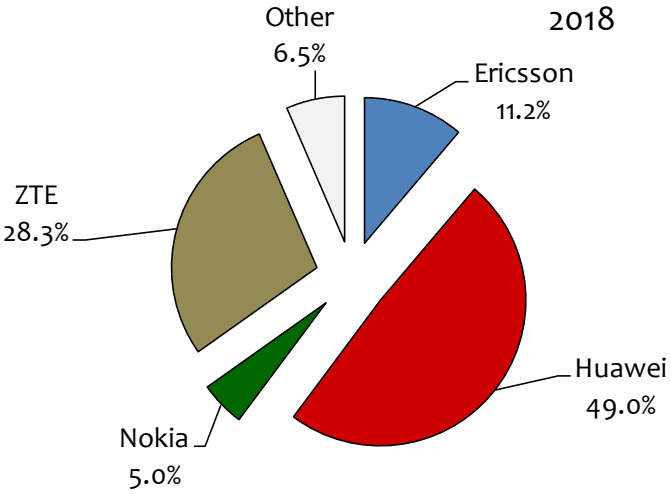
The following charts show share of transceiver shipments for calendar 2018:

Chart 37: Overall Transceiver Shipment Shares, by OEM, 2018



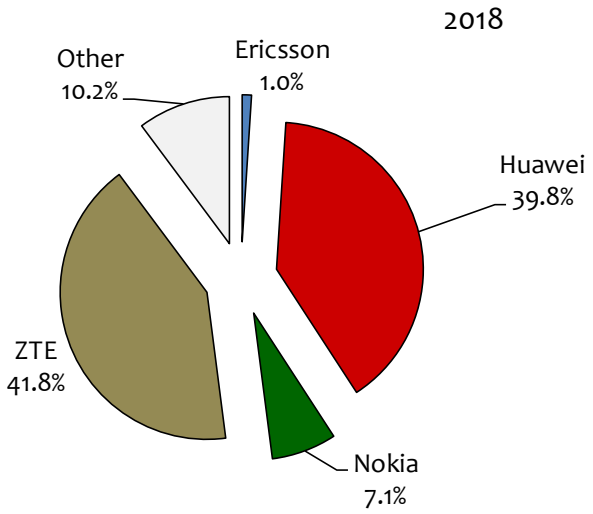
Source: Mobile Experts

Chart 38: GSM/EDGE Transceiver Shipment Shares, by OEM, 2018



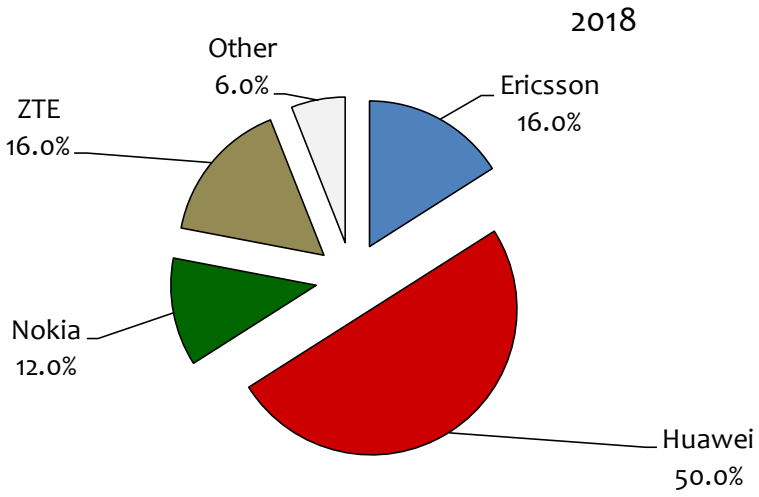
Source: Mobile Experts

Chart 39: CDMA/EVDO Transceiver Shipment Shares, by OEM, 2018



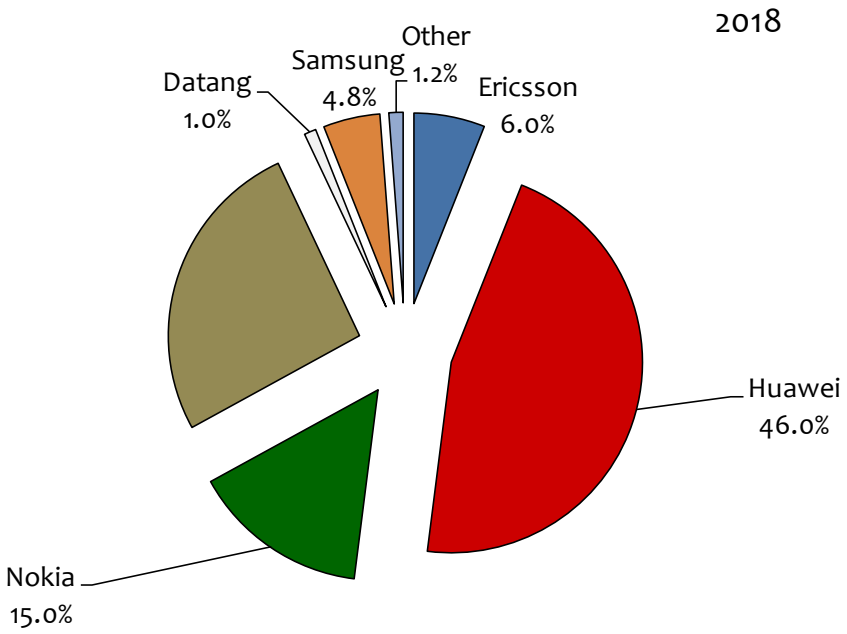
Source:, Mobile Experts

Chart 40: WCDMA/HSPA Transceiver Shipment Shares, by OEM, 2018



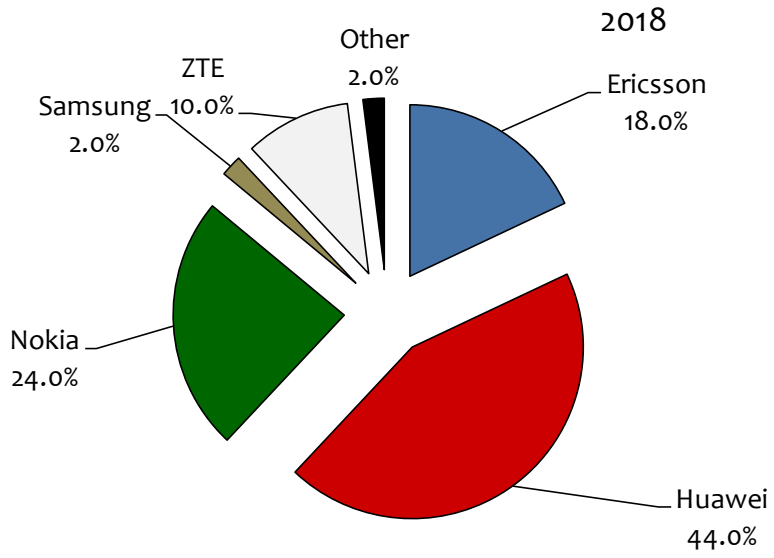
Source: Mobile Experts

Chart 41: TD-LTE Transceiver Shipment Shares, by OEM, 2018



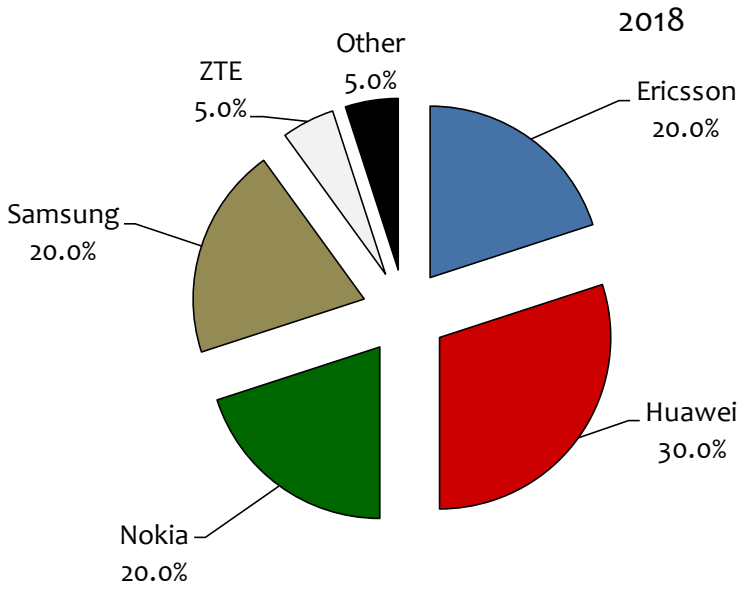
Source: Mobile Experts

Chart 42: LTE-FDD Transceiver Shipment Shares, by OEM, 2018



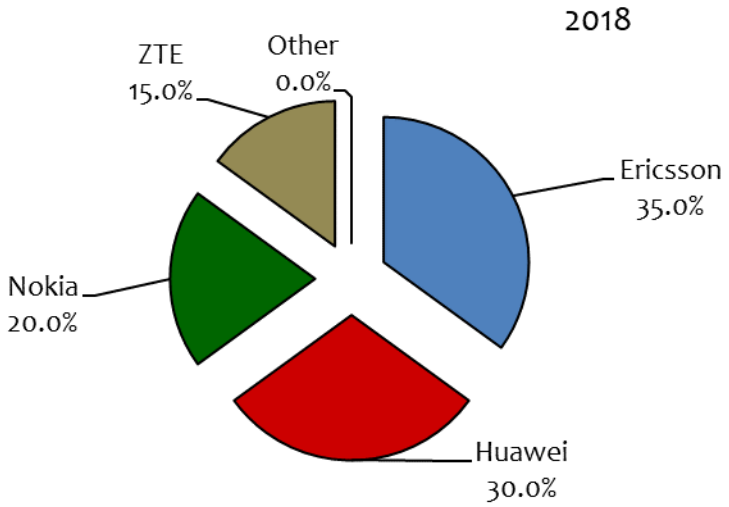
Source: Mobile Experts

Chart 43: 5G NR < 6 GHz Transceiver Shipment Shares, by OEM, 2018



Source: Mobile Experts

Chart 44: NB-IoT Transceiver Shipment Shares, by OEM, 2018



Source: Mobile Experts

SECTION 9: DEFINITIONS AND METHODOLOGY

To create estimates and forecasts for Macro Network equipment shipments, Mobile Experts relied on direct input from more than 30 industry sources, plus 25+ different mobile operators contributing to the overall analysis to give a detailed global view of the market. Mobile Experts built a "top down" forecast based on direct input from mobile operators and based on trends in end-user demand for mobile services and specific plans for base stations. Then, Mobile Experts built a "bottom up" forecast through discussions with the supply chain. Notably, multiple key semiconductor suppliers have been willing to share shipment data with Mobile Experts, to confirm our shipment figures for 2018 and backlog estimates for 2019. Mobile Experts also used financial disclosures from publicly traded companies to confirm our quantitative view of the equipment market.

Mobile Experts defines the macro base station market with strict technical criteria, to keep it separate from the small cell and DAS equipment markets. Specifically, radio equipment is counted in the "Macro" category if the composite power for a sector exceeds 40W. In this definition, macro base stations may be omnidirectional, or sectorized… although almost all are sectorized. The transceivers counted in this study include transceivers in active antenna arrays (AAS), in remote radio heads (RRHs), and integrated into base station cabinets.

A "base station" is defined as the equipment supporting a single Macro site and a single frequency band: it refers to a baseband processing "unit" of capacity plus a number of Remote Radio Head units. Theoretically a site will have three RRH units per site, but in practice the number for LTE networks is 4.2 RRHs per BBU.

Because the definition of a base station is not crisp with regard to radio hardware, we use the number of RRH or RU units as our initial count for deployment, and then we verify the accuracy of these numbers by comparing the number of components supporting RRH/RU units.

A Transceiver is defined as a physical radio transmitter path and all of the receivers that are related, including the main receiver, diversity, sampling, and sniffing receivers. To be clear, a 64T64R radio box contains 64 transceivers. A 1T2R radio box contains one transceiver, despite two receivers for diversity.

A Remote Radio Head is defined as a physical box which converts a digital I/Q data stream into transmitter and receiver signals and boosts the transmit signal to the desired power level. A base station is considered to use the RRH architecture if CPRI, OBSAI, ORI, or any similar serial I/Q data stream is utilized between baseband

processor and radio unit. We use the term RRH to refer to 2G thru 4G equipment, and RU to describe 5G radio units, because of the change in approach to include PHY/lower MAC baseband processing in 5G architectures.

Market shares are listed as the share of transceiver shipments in all cases, not as the share of revenue. Base station revenue is priced as a combination of hardware, software, and services, so the revenue associated with hardware is arbitrary, and traditional definitions of "base station market share" are meaningless. Therefore Mobile Experts simply reports the share of transceiver shipments that we track through component vendors and operator inputs.

North America:	USA and Canada
Latin America:	Mexico through South America, including Caribbean
Europe:	Western and Eastern Europe, including Russia
China:	China, including Tibet and Hong Kong
Asia Pacific:	India through Australia/Micronesia, excluding China
Middle East/Africa:	Pakistan and Turkey through Africa
Multimode:	Capable of multiple simultaneous air interface standards (LTE, HSPA, GSM, etc)
Adaptable:	Capable of one air interface standard at a time, but reprogrammable
Single-mode:	Capable of only one air interface standard
Multiband:	Capable of operating in multiple frequency bands, one at a time
Carrier Aggregation Units:	Units which operate in multiple bands simultaneously

Figure 3. Key defnitions for regions and transceiver types

Source: Mobile Experts

Base Station:	A set of equipment which performs baseband processing to support mobile radio transmissions above 40W composite power, including BTS, nodeB, and enodeB types. NOTE: A Base Station Shipment can include a physical base station or simply a software upgrade so this metric can be misleading.
Transceiver:	An electronic assembly including transmitter (from DAC to modulated output) and one or more receiver chains (from antenna input to ADC). E.g. A 2x2 MIMO channel uses two transceivers at the base station. Note that a dual-band radio with one ADC/DAC and PA covering two bands will be counted as a single transceiver. A transceiver is equivalent to one spatial stream in this forecast.
2T2R, 4T4R, etc.	This numbering system refers to the number of transmitters and receivers associated with a single RU. For mobile infrastructure, the number of downlink transmitters is listed first, and the number of uplink receivers is listed second. In this way the RRH/RU is described by the number of physical transceivers, not the MIMO order.
MIMO:	In this forecast MIMO is categorized according to downlink configuration. MIMO order is designated by n x m, where n=number of transmit antennas and m=number of receive antennas. The MEXP forecast designates the number of distinct MIMO streams.
AAS:	Active antenna systems refer to beamsteering systems, with multiple antenna elements transmitting the same signal, phased for beamsteering control.
IAR:	Integrated Antenna Radio systems involve the physical integration of antennas with transceivers. Not all IAR systems result in beamsteering, and not all beamsteering systems use IAR.
MIMO Beam:	All Integrated Antenna Radio units are evaluated for the number of "beams" transmitted. Each beam represents a directional transmission/reception from the antenna array. For an IAR, a single beam can be used (simple fixed antenna configuration) or up to 16+ beams can be transmitted. The number of beams is typically less than 1/4 the number of antenna elements.
MU-MIMO Stream:	Each MU-MIMO stream represents a single logical flow of data from the baseband processor. A 2x2 MIMO link uses two MIMO streams, and a 4x4 MIMO link involves four MIMO streams.
CA:	Carrier Aggregation, in this forecast, refers to inter-band Carrier Aggregation and not to Intra-Band Carrier Aggregation.
Shipment Share:	Note that this forecast does NOT report traditional "Market Share" calculated by revenue. Instead Mobile Experts reports the share of transceiver shipments for each vendor.
Ultra High Densit	Traffic density above 0.1 Gbps/km2/MHz
High Density:	Traffic density between 20 and 100 Mbps/km2/MHz
Mid Density:	Traffic density between 5 Mbps/km2/MHz and 20 Mbps/km2/MHz
Rural:	Traffic density below 5 Mbps/km2/MHz

Figure 4. Key defnitions for other terminology

Source: Mobile Experts